TECHNICAL REPORT H-76-13

BEACH NOURISHMENT TECHNIQUES

Report 1

DREDGING SYSTEMS FOR BEACH NOURISHMENT FROM OFFSHORE SOURCES

by

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Beach nourishment
Dredged material disposal
Offshore operations

This report presents the results of the first two phases of a research
project aimed at developing new dredging systems for beach nourishment from
offshore sources. As an introduction to the subject matter, the current situ-
ation in the United States regarding beach nourishment and offshore dredging
equipment is outlined. Example nourishment projects are described in order to
illustrate the types of nourishment projects accomplished and the range of
equipment used to date. Next, the engineering considerations involved in
selecting an optimum nourishment system for a particular project or project category are presented, and their effects on system characteristics are discussed. The main body of the report presents the results of an investigation into equipment suitable for offshore nourishment work. Approximately 50 examples are described illustrating dredge types, pipelines, connections, and miscellaneous pieces of equipment. The examples are divided into the main categories "existing" and "proposed" and subdivided according to design concept. The final portion of the report consists of the selection of certain equipment subcategories for further consideration and the construction of possible offshore nourishment systems using this selected equipment. A logic network is presented outlining these possible systems, and their projected uses are discussed. Future phases of the research project are outlined. The report includes approximately 45 illustrations and 85 references directly related to offshore dredging and beach nourishment.
The study reported herein was conducted using funds provided by the Operations Division, Office, Chief of Engineers (OCE) under the auspices of the Investigation of Operations and Maintenance Techniques (IOMT) program. Mr. Milt Millard was OCE Technical Monitor for this work.

The study was conducted during the period February 1973 through August 1975 in the Hydraulics Laboratory of U. S. Army Engineer Waterways Experiment Station (WES) under the general supervision of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory; F. A. Herrmann, Jr., Assistant Chief of the Hydraulics Laboratory; R. A. Sager, Chief of the Estuaries Division; E. C. McNair, Jr., Manager of the Research Projects Group; and T. W. Richardson, Project Engineer. Mr. Richardson performed the investigations described herein and prepared this report.

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Directors of WES during this study and the preparation and publication of this report were BG E. D. Peixotto, CE, COL G. H. Hilt, CE, and COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.
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BEACH NOURISHMENT TECHNIQUES
DREDGING SYSTEMS FOR BEACH NOURISHMENT FROM OFFSHORE SOURCES

PART I: INTRODUCTION

The Problem

1. Any littoral cell, as defined by Inman and Frautschy, requires sources of material for its sediment budget, and coastal erosion is often one of these sources. Problems occur, however, when coastal erosion conflicts with man's activities. Losses of property, structures, and recreational areas are the most common results of this conflict. The magnitude of coastal erosion in the United States is reflected in the findings of the National Shoreline Study, which classified 4350 km* of shoreline as "critically eroding." The fact that man himself often causes the erosion further complicates the situation. Whatever the cause, coastal erosion is a serious problem whose severity will increase in the near future.

2. What are some ways of coping with an eroding coastal area? One approach is simply to allow the erosion to continue, while recognizing and planning for its eventual effects. Such a philosophy is often employed where the cost of controlling coastal erosion would outweigh the benefits to be gained. The National Shoreline Study, in fact, concluded that "land use controls and other management techniques" might be acceptable means of dealing with existing erosion along 28,650 km of U. S. coastline. The National Park Service recently adopted such a policy for its coastal parks along the Outer Banks of North Carolina.

3. For many coastal areas, however, the possible losses from erosion can well justify the expense of efforts to control it. Since

* A table of factors for converting metric (SI) units of measurement to U. S. customary units is presented on page 3.
erosion consists simply of natural forces removing more material from an area than they contribute, these efforts can be designed for one of two purposes: they can either slow the rate of removal or boost the rate of contribution.

4. In the past, coastal erosion control leaned toward the first purpose. Attempting to slow the removal of material resulted in the sometimes haphazard construction of groins, breakwaters, seawalls, and other structures. As is now recognized, however, slowing the removal of material from one area of a littoral cell will often slow the rate of contribution to other areas. Therefore, the net effect of many such erosion control efforts was simply to shift the erosion to other locations. Examples of such a situation are numerous. Bruun and Manohar, for instance, estimate that over one-third of Florida's coastal erosion can be attributed to "man-made littoral barriers," many of which were constructed to combat coastal erosion.

Beach Nourishment

5. Boosting the rate of contribution to an area, commonly known as nourishment, is the other basic approach to coastal erosion control. For the purposes of this report, nourishment will be divided into three categories:

a. Restorative—contribution of a large quantity of material in a short period of time, for the purpose of rebuilding an eroded area.

b. Periodic—intermittent contribution of material, usually on a regular basis.

c. Continuous—relatively constant contribution of material.

6. Increasingly, coastal erosion control projects are incorporating one or more of these nourishment categories as the primary approach to solving an erosion problem. The National Shoreline Study, for example, estimated a yearly cost of $73 million for recommended nourishment of critically eroding areas. There are several reasons for this trend. First, nourishment avoids many problems caused by purely structural solutions (groins, seawalls, etc.), since it combats erosion with a
different approach. Second, results can usually be achieved fastest by nourishment. Third, the cost of a well-planned nourishment project is often competitive with other means of erosion control. Fourth, a pure nourishment project rarely detracts from an area's aesthetic appeal, since the end result is a rebuilt coast and nothing more. Finally, nourishment is preferable because of the lower potential for adverse effects. In blunt terms, it's hard to hurt an eroding area by adding material to it.

7. Thus far, the topic of coastal erosion has been addressed in general terms such as "coastal areas" and "material." However, the problem of U. S. coastal erosion can be reduced to more specific terms. The coastal areas of major concern are beaches, and the eroding material is sand. This does not imply that the erosion of bluffs, marshes, and other types of coastal areas is an insignificant problem. It simply means that beaches are of prime importance due to their high desirability and relatively limited occurrence. A beach in good condition serves not only as a recreational area but as excellent protection against storm damage to adjacent areas. Coastal land development often centers on beach areas, with resulting high property values. Yet, according to the National Shoreline Study, only 33 percent of the U. S. shoreline, excluding Alaska, has any form of beach.

8. The topic of discussion, then, can be narrowed to the nourishment of beach areas in the U. S. The two main components necessary to any beach nourishment project are: (a) a source of sand and (b) a means of moving this sand to the beach. The required characteristics of the source area itself are simple to state but sometimes difficult to achieve (for a discussion of desirable sand characteristics, see Reference 5, Section 5.332): all source areas should be of minimum ecological importance and should be located such that removal of sand will not produce adverse effects. Many other considerations, such as source size, distance to project site, and physical working conditions, influence the selection of a source area. However, the above two criteria are perhaps the most limiting on a nationwide basis.

9. A search for sand sources capable of meeting these criteria
and supplying sufficient sand quantities for future work inevitably leads to one area: the U.S. inner continental shelf. Particular projects may find other sources more suitable, but there is little doubt that the general trend of a nourishment program such as that recommended by the National Shoreline Study would be toward offshore sources. The U.S. Army Coastal Engineering Research Center (CERC) has, in fact, been conducting the Inner Continental Shelf Sediment and Structure Survey (ICONS), formerly called the Sand Inventory Program, since the mid-1960's. The purpose of this survey is "to find and delineate offshore deposits of sand suitable for beach restoration and stabilization." 6

10. The topic of this report, therefore, can now be further narrowed to beach nourishment from offshore sources. Since the problem of finding suitable sand sources is being addressed by ICONS, the remainder of this report will deal with the second component of a beach nourishment project, i.e., the means of moving sand to a beach, as applied to offshore operations.

11. Any system designed to accomplish offshore beach nourishment consists of three basic components: (a) equipment to recover sand from the source, (b) equipment to transport sand from the source area to the project area, and (c) means of distributing sand within the project area. In this report, component 3 will be considered only to the extent that it influences equipment used in components 1 and 2.

Example Nourishment Projects

12. To provide a background for the discussion of offshore nourishment, it is necessary to have some familiarity with the general range to date of nourishment project types and the equipment used in their accomplishment. Each of the following examples illustrates a particular nourishment category and/or a different type of nourishment system.

13. One of the largest and most successful restorative nourishment projects was conducted in Harrison County, Mississippi, in 1950-51. The project consisted of repairing an existing seawall and restoring badly eroded beach along 40 km of Gulf Coast shoreline. Two hydraulic
dredges placed almost 4.6 million cubic metres of sand on the beach through pipelines. The sand was obtained by dredging a channel 4.3 m deep in Mississippi Sound. The channel was located approximately 460 m from and parallel to the shoreline. A survey of the project 7 yr after completion showed little net sand loss from the fill area. Both borrow and project sites were located in relatively sheltered areas.

14. An example of periodic nourishment at Virginia Beach, Virginia, was described by Bunch. Sand for periodic nourishment was dredged from Owl Creek Estuary and pumped a maximum distance of 4.6 km through a partly submerged pipeline. A small (25 cm) hydraulic cutter-head dredge was used to dredge the sand. Two booster stations, one of them floating, were used along the pipeline. Annual nourishment requirements were estimated by Bunch to be at least 108,000 cu m along 5.3 km of shoreline.

15. Continuous nourishment is often considered synonymous with stationary sand bypassing, which is the artificial movement of sand by a fixed installation past an obstacle in the coastal zone. One of the most successful examples of a stationary sand bypassing plant is the installation at Marina di Carrara, Italy. A dredge mounted on a circular pier picks up sand trapped by the Marina di Carrara harbor jetty. The sand is pumped a maximum distance of 6 km through a 25-cm, land-based pipeline by four automated booster stations. The sand is discharged at various points along the pipeline to nourish the beach between Marina di Carrara and Marina di Massa. The small (100 cu m/hr) capacity of the system is characteristic of many stationary bypassing plants, which are usually sized to handle an average littoral drift rate.

16. A restorative nourishment project unusual in several aspects was accomplished in 1969-70 at Copacabana Beach, Rio de Janeiro, Brazil. First, a hydraulic model of Copacabana Beach was constructed at scales of 1:300 horizontal and 1:75 vertical. Using crushed bakelite as the modeling material, several methods of nourishment were studied and evaluated. As a result of the model study, a nourishment method was selected which combined dumping by a hopper dredge with direct placement of sand on the beach by pipeline from two cutter suction
dredges. The cutter suction dredge operation began first, with the two dredges pumping a total of 1,500,000 cu m of sand a distance of up to 5 km. Each dredge had a separate floating pipeline with a floating booster station. The two floating pipelines were connected to two land-based pipelines which ran parallel through Rio de Janeiro, terminating in six discharge points along the 4.0-km stretch of beach. A third land-based booster was added where the pipes initially entered the beach. The hopper dredge operation began about 2 months after the start of the cutter suction dredge portion. A 3,000-cu-m capacity hopper dredge equipped with horizontally sliding bottom doors picked up sand approximately 4.3 km offshore. It then approached the beach until the bow grounded, at which time the forward hopper doors were opened. This lightened the dredge, which then moved forward, repeating the operation until all hoppers were emptied. Approximately 2 million cubic metres of sand were delivered to the beach in this manner, providing one of the few successful examples of beach nourishment by dumping.

17. The final example of a nourishment project is the periodic nourishment at Santa Barbara, California, an operation which began in 1938 with the stockpiling of approximately 385,000 cu m of sand along 1.2 km of beach east of Santa Barbara Harbor. The sand was dredged from the harbor where it had settled due to the effects of a breakwater built in 1929. The stockpile serves as a sand source for beaches farther east and is replenished at 2- to 3-yr intervals by a hydraulic pipeline dredge performing navigational maintenance in Santa Barbara Harbor. The yearly rate of replenishment is roughly 230,000 cu m. The Santa Barbara project thus combines maintenance dredging with periodic nourishment in a bypassing type of operation.
18. Prior to describing equipment and systems for offshore beach nourishment, it is helpful to discuss some of the engineering considerations which influence the selection of an optimum system* (see Table 1 for a summary of these considerations). While the relative importance of these considerations will vary widely from project to project, they will usually apply in some degree to every beach nourishment project, whether offshore sand is utilized or not. However, it is assumed during this discussion that a suitable offshore sand source is available.

Project requirements and constraints

19. The first group of considerations can be described broadly as project requirements and constraints. The most obvious project requirements are the quantity of material to be used on the beach and the time available to do so. In a broad sense, the capacity of the system selected should be a direct function of these two factors, although there are exceptions. For restorative and periodic nourishment in areas of high erosion rates, for instance, a good case can often be made for using the largest capacity system available to minimize the quantity of extra sand that must be placed to compensate for erosion during the project. Another project requirement is the length of beach to be nourished. Usually, this consideration affects mostly the onshore sand distribution system. However, in cases of extreme beach length, some nourishment systems, such as those using pipelines, may be undesirable due to length or periodic relocation costs. Similar in nature to the length of beach requirement is the specified method of sand placement. If direct placement is used, then sand must be brought to points along the entire beach length. However, if the sand is stockpiled in one or two locations, allowing its distribution by natural forces, then perhaps a

* The term "optimum system" is defined as that system, either existing or conceptual, which best meets the engineering considerations of a particular project or project type.
different system would be desirable for the same project.

20. Constraints imposed on a project vary widely in their nature and effects. Possibly the most important from many standpoints are environmental constraints. These can influence not only the location of a borrow area but the type of equipment used to recover the sand and place it on the beach. As previously discussed, offshore nourishment projects generally have less trouble meeting environmental constraints than projects which use bay or estuarine sand sources. However, water quality, aesthetics, and ecology can all be constraints when selecting an optimum system for offshore beach nourishment. For example, the suspension of solids by cutting devices can cause adverse effects on both water quality (excessive turbidity) and marine organisms (burying or suffocating them). Stringent aesthetic constraints can preclude the use of permanently installed pipelines and booster stations for continuous or periodic nourishment.

Borrow and project site characteristics

21. The second group of engineering considerations deals with the locations of and physical conditions at the borrow and project sites. Probably the most important consideration in this group is the distance from borrow site to project, which is a major factor in determining the optimum system for the project. For example, direct pumping of sand to the project by pipeline, a method often used, is feasible only up to certain pipeline lengths. Conversely, transportation by barge or hopper dredge requires a minimum haul distance to be economically competitive with other systems. Three important physical conditions influencing an optimum system for offshore beach nourishment are the average wave, current, and wind conditions at both the borrow and project sites. The most restrictive of these is the average wave climate, especially in the borrow area. When wave conditions are calm, almost any system can be used to recover and transport sand. A small increase in the average wave climate, however, drastically shrinks the list of feasible systems. Cutter suction dredges with spuds, for instance, cease to be effective when the significant wave height reaches approximately 0.3 m. The use
of swing wires instead of spuds raises this limit to around 0.75 m. The pontoon pipelines often used with this type dredge are similarly sensitive to wave conditions. The effects of wind and currents on nourishment systems are less quantifiable than wave effects, but relative evaluations can still be made. Water depth at the borrow site is a physical consideration which differentiates mainly between individual pieces of equipment rather than equipment types. Exceptions to this are conceptual designs for deepwater dredging and ocean mining at depths in excess of present capabilities.

**Borrow deposit characteristics**

22. A third group of engineering considerations affecting optimum system selection are the characteristics of the borrow material and the deposit itself. For instance, the degree of cementation or compaction of the borrow sand will determine whether cutting methods are required to recover it, as will layers of undesirable material on or in the sand deposit. If cutting is required, then pieces of equipment such as plain suction dredges or even hopper dredges may not be feasible. The thickness of the sand deposit affects system selection in an oblique, but important, way. By determining the area which must be covered to retrieve a certain quantity of sand, it can make mobile equipment such as hopper dredges or walking platforms more or less desirable. The relation between the grain size frequency distribution of the borrow sand and that of the existing sand at the project also has an indirect effect on system selection. The "fill factor" or "renourishment factor" as discussed by James determines the quantity of borrow sand which must be initially placed on the beach to achieve the desired amount of fill. Thus, for a nourishment project which requires a certain amount of sand to achieve the design profile, it might be necessary to move several times that amount of sand to the project. The effect on optimum system selection, then, is fairly obvious.

**Project locale characteristics**

23. The fourth group of engineering considerations are the characteristics of the area surrounding the project site. Since each project and the area surrounding it are unique, only a few of the more important
characteristics will be discussed. The first of these is the proximity of a sheltered area such as a harbor to the project. This characteristic can influence the selection of an optimum system in several ways. A sheltered area adjacent to the project site, for instance, can be used for rehandling of sand by nonseagoing dredges or as a location for direct pumping to the project from a hopper dredge. A sheltered area in the vicinity of the project can be used as a place of refuge during storms for equipment which could not survive open-water conditions. The lack of such shelter might preclude the use of equipment which would otherwise be suitable. Another characteristic to be considered is the bottom topography from the project site seaward. This dictates how close to the project equipment such as hopper dredges can come before grounding, thereby determining the distance material must be transported if rehandling techniques are used. Also, a shallow, gently sloping bottom can preclude the use of equipment such as a semisubmersible dredge which might require deeper water to operate effectively.

**Economic considerations**

24. The final selection of an optimum system for an offshore beach nourishment project rests, of course, on one consideration--economics. Which system will accomplish the project at the least cost? Every engineering consideration discussed thus far eventually leads to this question. The ability to answer it depends largely upon being able to predict the relative performance of various systems in a given situation. Unfortunately, for most offshore nourishment systems, both conceptual and existing, there is little concrete data on which to base such a prediction. The effects of offshore operation on existing equipment are not yet quantifiable, and the predicted performance of conceptual equipment is always open to some question, no matter how experienced the designer. Therefore, the process of evaluating and comparing various offshore nourishment systems must necessarily include, at present, a large measure of the evaluator's subjective judgment. With this in mind, the equipment for offshore beach nourishment systems can be described and discussed.
Equipment

25. Equipment for offshore beach nourishment work is grouped into two categories—existing and proposed. Existing means simply that the equipment has been built and actually used (not necessarily on a beach nourishment project). Whether it performed adequately often depends upon an individual's viewpoint; therefore, this is not a requirement for the category "existing." Proposed means that the equipment is either still on the drawing board or else has been built but not yet used. Each of these categories has two subdivisions, which were discussed previously: (a) equipment for recovering sand from the source, and (b) equipment to transport sand from the source area to the project. Some equipment fits both subdivisions.

Existing dredges

26. The first class of equipment, and probably the largest, to be discussed is existing equipment for recovering sand from an offshore source. This equipment recovers sand in one of two ways: (a) by mechanical means, where sand is dug from the bottom and carried to the surface by some type of container, or (b) by hydraulic means, using the velocity energy of flowing water to carry sand to the surface through a conduit. For the purposes of this report, mechanical dredges will be assumed to employ either a grab, drag, or bucket as the sand container.

27. Grab dredges (Figure 1) are similar in many ways to land-based equipment; in fact, a small grab dredge can consist of a portable crane with a clamshell grab loaded onto a barge. The grab dredge can work in moderate wave conditions, since it has no rigid contact with the bottom. It can load either its own hoppers, if such exist, or barges for transporting sand from the source area. Most grab dredges have a relatively low production rate, which decreases with increasing water depth. However, some such as those used for tin mining in Southeast Asia are capable of substantial production rates in deep water. Cost of operating a grab dredge does not increase with depth as fast as for other dredge types. Sand can be recovered in almost any degree of cementation, although the dredging efficiency decreases with increasing
cementation. Although the grab causes little agitation at the bottom, fine material can wash out as the grab is raised to the surface, creating some turbidity. The mobility of grab dredges is usually limited, although some are self-propelled and therefore more mobile. Since a grab dredge operates most efficiently in shallow water, using it close to shore is desirable. Most existing grab dredges are not designed for offshore work and would therefore require a nearby sheltered area for storm protection. No examples are known of grab dredges used for offshore beach nourishment. Reference 22 describes grab dredges used in sand and gravel mining.

28. At least one example is known of a drag-type dredge (Figure 2) being used for an offshore nourishment project. The equipment consisted of a three drum hoist operating from shore, with cables running to an anchor barge approximately 300 m offshore. A 2.3-cu-m capacity drag scraper was pulled shoreward on the cables, recovering sand from a zone 185 to 245 m offshore. The results of a study of this nourishment technique are discussed in Reference 24. In brief, it was determined that the pits dug offshore by the scraper filled primarily with littoral drift sand and sand from a "shoulder bar" which formed at the updrift
edge of the pit during digging operations. Only the finer fraction of sand placed on the beach was observed to return to the pits, and no major beach stability problems were observed to occur due to digging operations. Reference 25 describes a patented, truck-mounted drag scraper which operates in a similar manner. The drag-type dredge has possible uses for projects where the sand source is close to shore and where a small production rate would be applicable. Many of the comments about grab dredges apply to drag-type dredges, except that a land-based dredge would not require a nearby sheltered area.

29. Bucket dredges exist mainly in one configuration—the bucket ladder dredge (Figure 3). Bucket ladder dredges use an endless chain of
buckets running over a rigid frame to dig and raise sand. Their production rate, which in sand is primarily a function of bucket size, is little affected by increasing water depth. The larger dredges have buckets with capacities of 0.3 cu m or more. The maximum digging depth of the bucket ladder design, due to the increasing weight of the buckets and ladder, is somewhere in the neighborhood of 45 m. A bucket ladder dredge can easily dig cemented sand but is limited to mild wave conditions due to the rigid ladder. The bucket ladder dredge can be economically competitive with other equipment of similar capacity. Usually, it is limited to loading barges for transportation to shore. Some bucket ladder dredges, however, empty their buckets into a shipboard sump, where a pump rehandles the sand and moves it to shore through a pipeline. Most existing bucket ladder dredges are not self-propelled nor designed for offshore work; hence, mobility is limited and a sheltered area nearby would be needed for an offshore nourishment project. As with the grab dredge, fine material can wash out as the buckets return to the surface, creating some turbidity. Suspension of solids by bottom agitation, however, is minimal. Only one example is known of an offshore beach nourishment project where a bucket ladder dredge was used. The bucket ladder dredge in this case dug the sand and loaded it into self-propelled hopper barges. The sand was rehandled closer to shore and pumped to the beach via a pipeline. Approximately 200,000 cu m of sand was handled at an average rate of 7500 cu m per working day. Existing bucket ladder dredges have possible uses in offshore nourishment projects where wave conditions are mild, the required production is small to medium, barges are a feasible method of transporting sand, and a sheltered area is nearby.

30. Existing hydraulic dredges cover a gamut of configurations and capacities. Most fall into one of three design categories, but a few defy classification. Perhaps the simplest of the three design categories is the plain suction hydraulic dredge (Figure 4). The distinguishing feature of this type of dredge is its use of a long suction pipe to dig and raise sand to the surface. Digging may be supplemented by water jets at the suction pipe mouth that agitate bottom material.
However, plain suction dredges work best in free-flowing sand where gravity can feed the suction pipe. Plain suction dredges may have either flat bottom, bargelike hulls, or ship-type hulls. They are generally used where they can remain stationary for long periods of time, and are usually not self-propelled. Individual dredges may be designed either to load their own hoppers, to load barges, or to pump through a pipeline. The lack of need for a heavy ladder has allowed some plain suction dredges to be built that can recover sand at depths far exceeding the capabilities of most other types of equipment. Some have been built to dredge in moderate to heavy wave conditions, and at least one is designed to remain on station during storm conditions. Those dredges not designed to such standards, however, would require the protection of a sheltered area. Operating in free-flowing sand, the plain suction dredge usually causes little solids suspension. The use of water jets can create significant turbidity near the bottom; turbidity at the surface can occur due to the overflow of fines-bearing water from hoppers or barges. Also, the plain suction dredge tends to create deep holes in the borrow area, which can be ecologically undesirable. Minimum operating depth is limited only by the dredge's draft, which is small when a
flat-bottom hull is used. The plain suction dredge can be designed for almost any production capability, and can be relatively economical to operate under the proper conditions. An example of offshore beach nourishment using a plain suction dredge is given in Reference 28. The dredge had a flat-bottom hull, moved on anchor wires, and pumped sand approximately 400 m to shore through a part-floating, part-submerged 40-cm pipeline. The suction head was fitted with water jet nozzles to fluidize the sand and a jet pump to provide additional head in the suction pipe. A total of 1,070,000 cu m of sand was pumped to shore during this project. The diversity of plain suction dredges makes it hard to generalize as to their use in offshore beach nourishment projects. Those dredges which do possess offshore capabilities, however, are suited for projects having free-flowing, thick sand deposits, especially if pumping to shore is a feasible means of transportation. Deep water at the sand source can increase the relative feasibility of the plain suction dredge.

31. The second category of existing hydraulic dredges is the cutter suction dredge, probably the most common type of dredge in the world. Cutter suction dredges with almost exclusively flat-bottomed hulls (Figure 5) are more uniform in configuration than plain suction dredges. Their distinguishing characteristic is a rotating cutterhead.

Figure 5. Cutter suction dredge (with spuds)
at the suction pipe entrance which is used to cut or agitate the mate-
rial being dredged. The weight of this cutterhead and its drive machin-
ery and the forces required to dig into hard material are carried by a
heavy, rigid ladder connected to the hull and extending to the suction
pipe entrance. The ladder limits most cutter suction dredges to use in
mild to moderate wave conditions, since it can be slammed against the
bottom by the moving hull. It also effectively limits a cutter suction
dredge’s digging depth by exacting a heavy toll in additional weight for
increases in ladder length. Cutter suction dredges are normally nonself-
propelled and anchor themselves either by spuds or wires. Those using
spuds, which are long steel legs providing a rigid connection between
the dredge hull and the bottom, are more susceptible to wave action than
those using wires; however, with either system, mobility is, at best,
mediocre. The cutter suction dredge can easily dig the most cemented
sand, although it can cause considerable bottom agitation while doing
so. It is normally used in conjunction with a pipeline to move sand to
shore. Cutter suction dredges are built in all sizes and production
capabilities, from the smallest portable dredge to ones with 90-cm-diam
discharge lines. Most existing cutter suction dredges would require a
sheltered area near an offshore beach nourishment project. More off-
shore nourishment projects have used cutter suction dredges than any
other type of dredge; this is mostly an indication of the cutter suction
dredge’s widespread usage, not necessarily of any suitability for off-
shore work. A typical offshore project is described in Reference 29.
The cutter suction dredge operated approximately 0.8 km offshore and
pumped 245,000 cu m of sand to shore through a floating pipeline. An
unusual feature of the project was the transportation of well over half
the sand by truck from its initial point of deposition by the pipeline
to its final project location. The cutter suction dredge, therefore,
can be used for offshore nourishment projects. The conditions for its
use, however, are somewhat restrictive (mild wave climate, moderate
water depth, nearby sheltered area, and cemented or compacted sand) to
make it advantageous over a plain suction dredge. Pipeline transporta-
tion of sand to shore should be feasible, also.
32. The third main category of existing hydraulic dredges is the self-propelled hopper dredge (Figure 6). This dredge is by far the best suited for offshore work of the three dredge categories. It consists of a ship-type hull with hoppers to hold material dredged from the bottom. The material is brought to the surface through a suction pipe called a dragarm, which trails the dredge as it moves forward. Material enters the suction pipe through the draghead, whose configuration varies with the type of material being dredged. The draghead can be designed to agitate or cut cemented material. Most modern hopper dredges have one or two dragarms mounted on the side of the ship, although there are some older designs with one arm in the center of the hull or at the stern. At least one existing hopper dredge has four dragarms, two operating through the hull bottom and two on the sides. The dragarms can be fitted with swell compensators to increase efficiency in heavy seas. Hopper dredges have been built with hopper capacities from several hundred to slightly over 9000 cu m. The hoppers are usually unloaded by dumping through gates in the bottom of the ship, although some dredges have the capability of pumping out their hoppers. Hopper dredges are extremely mobile and do not require a sheltered area near the project unless the sand is to be rehandled or pumped out. These advantages do not come cheaply, however, as hopper dredges are relatively expensive to build and operate. Also, their use in offshore nourishment projects

Figure 6. Self-propelled hopper dredge with trailing dragarm
often requires rehandling the sand to move it ashore. The Copacabana Beach nourishment project described earlier circumvented this problem successfully, but so far attempts at offshore dumping in the United States have failed. When loaded, hopper dredges can draw a considerable amount of water, and the use of swinging doors to empty the hoppers further increases their minimum operating depth. Horizontally sliding hopper doors, such as used on the Copacabana dredge, allow dumping in shallower water. At least one hopper dredge has been fitted with a submerged pump at the draghead, thus overcoming the barometric pressure limitation and allowing a digging depth of around 30 m. Most existing hopper dredges, however, can dig no deeper than 18 to 21 m. The effects of hopper dredge operation on the environment depend somewhat on the type of sand being dredged. The draghead will create some turbidity at the bottom, although not as much as a cutterhead. In loading the hoppers, however, the overflow water can carry material overboard, creating a turbidity plume. In clean, coarse sand this is not much of a problem, but sand containing a significant amount of fine material can cause noticeable turbidity. The hopper dredge’s method of mining a sand deposit, i.e., skimming a thin surface layer from a large area, may be ecologically preferable over dredging methods which create deep holes.

In summary, self-propelled hopper dredges are suited for offshore nourishment projects where wave conditions make other dredge types unfeasible, moderate water depths exist at the borrow site, and, in some cases, a sheltered area is nearby where rehandling or pumpout can take place. A long distance from the borrow site to the project increases the hopper dredge’s relative feasibility, as does a thin sand deposit covering a large area.

33. Further information on the conventional types of existing dredges, both mechanical and hydraulic, can be found in References 34, 35, and 36. In addition to conventional dredges, several pieces of non-conventional equipment exist which also deserve mention in a report on offshore nourishment. Reference 37 describes a type of dredge (Figure 7) used to recover sand from deposits with up to 15 m of silt and clay overburden, at depths up to 70 m. This type of dredge, of which at least
fives have been built, uses a device fitted with high-pressure water nozzles to penetrate the overburden. Once inside the sand deposit, other water nozzles agitate sand, causing it to flow to the suction intake. A jet pump at the intake provides sufficient head to raise the slurry to the surface, where a booster pump moves it up to 2 km through a pipeline; the slurry can also be loaded into barges. The digging/pumping device is supported by chains; and the nozzle water, jet pump water, and slurry are carried by flexible rubber hoses. These can all be disconnected from the dredge at various points along their length and tied to buoys, should sudden storms arise. After the storm, the dredge moves back to the borrow site, reconnects, and begins operation. Production of the largest dredge is approximately 250 cu m of solids per hour.

34. One of the two known manned, self-propelled, submersible dredges is described in Reference 38, and its operation in an offshore beach nourishment project is outlined in Reference 39. The dredge
(Figure 8), classed for operation in 30 m of water, moves on bulldozer tracks. Hydraulic motors run the tracks, a 12-m dredge ladder, the cutterhead, and the anchor spuds. Electric motors drive the hydraulic pumps, dredge pump, and other accessories. Power is supplied from shore via an underwater cable, and the sand moves to shore through a submerged pipeline, the forward part of which is flexible to allow movement of the dredge. Two operators run the dredge, entering through a tower in shallow water and a lock in deeper water. The dredge is designed to deliver 150 cu m of sand per hour with a 915-m discharge line. During its offshore beach nourishment test project, it pumped almost 50,500 cu m of sand to shore, although it experienced a substantial amount of operational difficulties.

35. The other manned, self-propelled, submersible dredge known to exist is described in Reference 40. The dredge (Figure 9) was designed and has been used for digging underwater trenches for pipelines. It consists of a large machinery chamber, a dredging arm with cutterhead, two large ballast tanks, and an operator’s chamber, all mounted on a skid frame. The dredge is towed to the digging site by a tender which also supplies electrical power and air through flexible lines. The operator submerges the dredge by adjusting its ballast tanks, up to a
rated depth of 73 m. The dredge moves on the bottom by means of two forward winches, while one trailing winch improves stability and provides a reversing capability. Material is pumped at a maximum rate of 190 cu m per hour either through two side discharge pipes or a pipeline. Three electric motors in the machinery chamber drive three hydraulic pumps which, in turn, run the cutterhead, dredge pump, winches, and other accessories. In one pass, the dredge can dig up to 2.4 m deep and from 2.7 to 4.6 m wide. The operator's chamber is at atmospheric pressure except when operators lock in and out.

36. A patented dredging system operated by compressed air is described in Reference 41. The system (Figure 10) operates on the positive displacement principle, with the compressed air acting as a piston. The pumping unit works on the bottom, and consists of three boiler-like pressure cylinders, each with a suction inlet on its lower end. Connection with the surface is normally by flexible hoses and cables only.
Compressed air is alternately pumped into each cylinder and allowed to escape under the control of a surface distributor. When air is escaping, ambient water pressure forces the material being dredged into the cylinder. When compressed air is pumped into the cylinder, a check valve closes the suction pipe and the dredged material is forced up the discharge line. The three cylinders operate in overlapping cycles. The only moving parts underwater are two rubber check valves and a floating valve in each cylinder. The system creates little turbidity and has no theoretical depth limitation as long as compressed air is available at a sufficiently high pressure. For deep dredging, the compressed air distributor can be placed near the pumping unit to minimize "dead air" in the supply lines. Booster stations for long distance pipeline transport are similar to the dredging unit, differing mainly by the addition of a hopper. The system is built in several sizes, with the largest rated at 555 l/sec of slurry under ideal conditions. A major advantage claimed by the manufacturer is the system's ability to dredge and pump slurry with a higher percentage of solids than is usually attained by ordinary hydraulic dredges. The system has been used in a variety of dredging
projects and several industrial waste disposal pipelines. The principle of airlift dredging is simple: air injected into a submerged suction pipe causes the fluid density inside the pipe to be less than that outside; therefore, water flows into and up the pipe, carrying solid material with it. The injected air provides all the energy required to raise solids to the surface; thus, production rate is a function of air injection rate. The airlift dredge (Figure 11) has been proposed as a deep ocean mining system for manganese nodules and was used in one operation off the Florida coast. The airlift has practically no depth limitation, as long as air can be supplied at sufficiently high pressures, and has no moving parts underwater. However, its production rate is relatively small, and its lifting capability is sensitive to changes in solids concentration. Similar in principle to the airlift dredge are systems which use recyclable light media such as kerosene or glass spheres to lower fluid density in the suction pipe.

38. The dredge described in Reference 46 and shown in Figure 12, although conventional in some ways, is sufficiently different to justify a separate categorization. The vessel consists of two ship-type hulls
Figure 12. Twin hull dredge (plain suction configuration)

joined by a common bow, with a well between the hulls where the dredge ladder is located. It is self-propelled and can convert itself into either a plain suction or cutter suction dredge. As a plain suction dredge, it can dig up to 40 m in open water, and is swell-compensated for 4 m of vertical movement. As a cutter suction dredge, it can dig to a depth of 27 m. The dredge is designed to be used in a stationary mode when operating offshore.

Existing transport

39. The second class of equipment to be discussed is existing equipment for transporting sand from the source area to the project. Outside of shore-based drag scrapers, this transportation can take place
in one of two ways: (a) through a pipeline or (b) by a transporting vessel. Considering transporting vessels first, the hopper dredge performs this function in addition to recovering sand. It is a rather expensive sand transportation vessel, since it carries a large amount of equipment not needed for simple transporting, and since recovery operations at the sand source cease while transportation is taking place. However, large quantities of sand can be transported in one load, in heavy sea conditions, and at cruising speeds of up to 14 knots. Once the hopper dredge arrives at the project site, several methods can be used to transfer the sand load to the beach. From the standpoint of the hopper dredge, the quickest method is to simply dump the sand through the hopper doors. The sand can then be rehandled, usually by a plain suction or cutterhead dredge, and pumped to the beach through a pipeline. If the sand can be dumped close enough to shore (as in the Copacabana project), rehandling may not be necessary. Reference 47 describes a beach restoration project in which hopper dredges dumped sand both at the project site in 3.0 to 4.6 m of water and nearby in deeper water, where the sand was rehandled and pumped to the project. The pipeline from the rehandling dredge ran under one of the busiest harbor entrances in the world, emptying with the aid of a booster in an area adjacent to the harbor entrance. Approximately 15 million cubic metres of sand were moved by this system in 1-1/2 yr. Another method, if the hopper dredge is so equipped, is to use its pumpout system to empty its hoppers and pump sand directly to the beach via a pipeline. While this method eliminates the need for a rehandling dredge, it also requires considerably more of the hopper dredge's operational time than simple dumping. Usually, the hopper dredge moors at a barge or dock in sheltered water to perform this operation, although one beach nourishment project at Sea Girt, New Jersey 48 was accomplished by mooring offshore of the beach at a barge connected to a submerged pipeline (Figure 13). The project was largely experimental, with approximately 190,000 cu m of sand being moved through the system in 19 working days. Another method used to unload hopper dredges involves the hopper dredge pumping its cargo into a stationary hopper barge, which in turn uses its pumps to move the
material through a pipeline to the desired location. Such a method has little, if any, cost advantage over direct pumping by the hopper dredge. Generally speaking, however, the hopper dredge can pump out its cargo faster into a barge than through a long pipeline. Reference 49 describes this operation in more detail.

40. Another type of transporting vessel is the hopper barge. As the name implies, this is simply a bargelike craft (Figure 14) with a large, open hopper to carry dredged material. The hull can be either flat-bottomed or semimolded. Some hopper barges are self-propelled, although more probably exist which are not. The majority have capacities of less than 750 cu m, although at least one manufacturer offers standard sizes up to 3000 cu m. Hopper barges are usually loaded by either grab dredges, bucket ladder dredges, or specially equipped suction dredges. They normally unload by dumping, either through bottom doors or by splitting along their longitudinal axis if so designed. They can also be unloaded by grab dredges or by suction dredges, which can then pump the load to its final location. Although hopper barges are slower and smaller than hopper dredges, their use as transporting vessels does not interrupt recovery operations at the sand source. Their shallower draft allows them to dump sand closer to shore, especially if the split type barge is used. Loading hopper barges, however, becomes more difficult as wave conditions increase. A land reclamation
project using hopper barges for long distance transport is described in Reference 50. Sand was recovered by a cutter suction dredge and pumped through a floating pipeline to a floating sand loader, which filled one of three 6000-cu-m capacity hopper barges. The sand loader was used in order to bypass problems associated with loading such large barges at the dredge. Once full, the barges were pushed by a tug to the land reclamation project, about 145 km away. At the project, the barges were unloaded by a suction dredge with a booster pump on the suction line. For both loading and unloading, the barges were moored and the loading or unloading apparatus was moved to the barge. Estimated production of the operation was around 1.5 million cubic metres of sand per year. It was also estimated that the barge-tug combination could operate in up to 3.0-m seas. Reference 27 describes the nourishment project at Portobello Beach, England (previously mentioned), which is one of the few offshore beach nourishment projects using hopper barges.

41. Pipelines can be an inexpensive means of transporting dredged material in sheltered waters. As with most other existing dredging
equipment, however, limitations quickly arise when they are used in open water. These limitations focus primarily on two areas: (a) the pipeline itself, and (b) connections between the pipeline and dredge or between different pipelines. Considering the pipeline first, there are basically two existing types—floating and submerged. A floating pipeline can be constructed in many ways. Usually, however, it consists of steel pipe sections mounted on pontoons and joined by either ball joints or rubber sleeves (Figure 15). The pipe is supported clear of the water, allowing easy inspection and maintenance. Changing the line length involves simply adding or removing pipe-pontoon sections. Reliability of this type of floating line, however, decreases rapidly when exposed to waves, especially if ball joints are used. Some decrease in wave response can be obtained by ballasting the line so that it has only a slight positive buoyancy. Reference 51 briefly describes an offshore beach nourishment project in which the floating pipeline had a 4.5-m-long rubber hose at every third pipe joint and ball joints at the others. Apparently, the line performed satisfactorily in the wave conditions.

![Diagram of Pontoon Pipeline](image)

Figure 15. Pontoon pipeline
encountered. For a more detailed description of pontoon pipelines, see Reference 34, pp 89-93.

42. Another type of floating pipeline, designed particularly for offshore use, is the flexible floating pipeline (Figure 16). This type of pipeline is relatively new to the dredging industry, although it has been used for years for unloading petroleum tankers offshore. Each pipe section consists of reinforced rubber hose covered with flexible flotation material. Steel flanges are molded into each end of a section. Reference 52 describes several applications of flexible floating pipelines in exposed waters. In one instance, the pipeline continued to function in 2.5-m seas, although the dredge had to cease operations; in another case, the flexible floating pipeline held a dredge which had broken loose from its moorings in a gale. The anticipated life of this type of pipeline is greater than that of steel pipe of comparable strength. The initial cost of a flexible floating pipeline, however, is considerably higher than that for a pontoon pipeline.

43. A submerged steel pipeline, resting on the ocean bottom, bypasses many of the problems encountered by floating pipelines in the offshore environment. Flexible joints are necessary only where the pipeline must make a sudden break in direction. The line does not interfere with navigation, and is aesthetically preferable to a floating pipeline. Due to the submerged line's immobility, however, a floating pipeline is usually used between it and the dredge; therefore, in actual applications the submerged pipeline system is often limited by a floating line's reliability. The submerged line can be subjected to drag, lift, and vibratory forces of considerable magnitude as a result of
currents and wave action, and scouring under the pipeline can quickly undermine its stability. However, in an offshore nourishment project, these effects can be lessened by orienting the pipe perpendicular to the predominant wave fronts. In some cases, the pipeline can be installed, removed, and shifted within the project area by filling it with compressed air, thus causing it to float. (Reference 34, pp 96-98, describes a procedure for this.) If the project is for periodic or continuous nourishment, however, it may be desirable to permanently install the pipeline by burying it, thereby avoiding most problems except scour and fluidization of the bed surrounding the pipeline. Reference 48 briefly describes the installation and use of a one-piece, 70-cm-diam, 610-m-long submerged pipeline for an offshore beach nourishment project. Reference 53 summarizes the effects of waves and currents on submerged pipelines.

44. For the purposes of this report, existing pipeline connections will be considered in two main categories: (a) connections between floating pipelines and dredges and (b) connections between surface equipment and submerged pipelines. Most existing dredges use a swivel elbow (Figure 17a) as the connection to a floating pipeline. The swivel elbow allows a large degree of horizontal movement, but cannot compensate for vertical motion due to wave action. Some dredges use a section of rubber hose (Figure 17b) instead of a swivel elbow. The rubber hose can flex in all directions, and is probably better suited for connections subject to wave action. It should be kept in mind, however, that most existing dredge-to-floating-pipeline connections are designed for use in protected waters, where the loads imposed on the connection are far less than those in open-water use. Reference 54 describes, in brief, some problems encountered by a contractor in attempting to use a conventional dredge and floating pipeline in the ocean. Among these problems were failure of the dredge-to-floating-pipeline and floating-to-submerged-pipeline connections.

45. Connections between surface equipment and submerged pipelines vary in design much more than dredge-to-floating-pipeline connections. Providing a reliable connection is a very complex problem; since one end
Figure 17. Floating pipeline connections
is fixed, the other end is subject to violent movement and may be acted upon by currents that vary in magnitude and direction over the length of the connection. Most often, these connections are between floating and submerged pipelines. Rubber hose was used for this purpose in the offshore beach nourishment project at Redondo Beach, California, described in Reference 28. Rubber hose is also used in the petroleum industry to connect single buoy mooring terminals to submerged pipelines. However, as described in Reference 55, the hose must be long enough to allow for tide and wave displacement, and should be equipped with flotation to provide support, prevent abrading on the bottom, and control its bending radius. Tensile loads on the hose should be minimized by the buoy anchoring system. Another type of connection between floating and submerged pipelines is described briefly in Reference 56. This connection (Figure 18) consists of a rigid pipe attached by ball joints to a surface float and a submerged, floatable base. The surface float has a quick disconnect coupling for attachment to the floating pipeline. The floatable base anchors the entire connection and is attached to the submerged pipeline. The base can be floated by filling its ballast tanks with air, and incorporates a 360-deg swivel to provide for movement of the connection in a horizontal plane. When described in Reference 56, this connection was being used for a harbor construction project in which it was planned to handle approximately 20 million cubic metres of sand. As mentioned previously, the offshore beach nourishment project at Sea Girt, New Jersey, described in Reference 48, incorporated a mooring barge connected to a submerged pipeline. The connection between the mooring barge and submerged pipeline (Figure 13) consisted of steel pipe sections oriented at right angles, with ball joints between the sections. The ball joints were limited to a swivel motion by restriction rings, and buoyancy tanks were installed around the pipe sections. The upper end of this connection was attached to the mooring barge and the lower end to a weighted sled at the end of the submerged pipeline. Several failures of the connection were experienced during the project.

46. The distance which sand can be pumped through a pipeline is limited by the available pumping energy. The dredge can supply a certain
amount of this energy, beyond which booster pumping stations are required. Floating booster stations have been used for years in the dredging industry, mostly in sheltered waters. A floating booster station is essentially a hydraulic dredge minus the digging, suction, and maneuvering apparatus. In fact, at least one dredge manufacturer designs his standard cutter suction dredges such that the pumping modules can be used separately as floating booster stations. Usually, a booster station is installed at an interval along the pipeline corresponding to the maximum pumping distance of the previous pump. It can also be installed
at or near the dredge, although this can create high pressures in the booster pump and discharge line.

**Proposed equipment**

47. The second major category of equipment for offshore beach nourishment is designated "proposed equipment." As previously mentioned, this classification covers not only "drawing board" ideas but equipment under construction or recently built but not yet used. Almost all of this equipment is designed for recovery of sand from the source. Very little appears in the literature or other sources on improved methods of transporting sand from the source area to the project. With this in mind, therefore, the subcategorization used for existing equipment, although still valid, will be set aside in favor of a classification more appropriate to the information being presented. Also, since the relative merits of proposed equipment cannot be discussed with much factual basis, the equipment simply will be described in as much detail as available information permits and conjectures will be made as to its possible employment.

48. Generally, proposed equipment for offshore dredging can be grouped into five subcategories, four of which describe the designer's basic approach to the design and the fifth being the standard catchall:

   a. Improved conventional
   b. Platform
   c. Submersible
   d. Semisubmersible
   e. Miscellaneous

49. Subcategory a, improved conventional, is composed of equipment similar to existing dredge plant but modified for use in the offshore environment. It also includes means of improving the performance of existing plant offshore. The first item to be discussed under this subcategory is a design for a swell-compensated cutterhead dredge, described in Reference 57. This dredge (Figure 19) would be similar in many respects to a conventional cutterhead dredge, the main difference being a ladder articulated at three points instead of the usual single trunnion at the hull. The two additional articulation points would be
located near the cutterhead, which would exert a constant force on the bottom by virtue of being supported by compensating hydraulic cylinders. The design also includes a submerged pump mounted on the ladder. Anchoring would be accomplished by wires. The designer claims operational capabilities in seas up to 1.6-m significant wave height, with a production rate in excess of 1500 cu m/hr. Such a dredge would have the advantage of being able to work in conventional operations as well as offshore. For offshore beach nourishment work, this design might be used where direct pumping to the beach is feasible. The mechanical cutting ability would be needed for cemented sands, overburdens, etc.

50. Reference 58 describes a design for a swell-compensated digging and suction apparatus, which would be mounted on a conventional hydraulic dredge in the same manner as a cutterhead ladder. The apparatus (Figure 20) would consist of a rotating bucket wheel at the end of a swell-compensated ladder, which would also support a suction pipe. The hydraulically driven bucket wheel would excavate bottom material which would then be drawn into the suction pipe and carried to the surface. Swell compensation would be provided by a parallelogram structure pretensioned by a cable connected to a shipboard piston compensator. As the dredge moved under the influence of wave action, the structure would move in a manner analogous to a draftsman's parallel rule. The section of suction pipe within the parallelogram would telescope, and
would be connected at both ends by ball joints. Possible uses for a
dredge equipped with such an apparatus would be similar to those dis-
cussed in the preceding section.

51. Another drawing board design for an offshore dredge* consists
of a self-propelled dredge with a ship-type hull and a long, swell-
compensated, plain suction pipe located in a midship well. The dredge
(Figure 21) would be designed for operation in a stationary mode at
depths up to 65 m and in seas with a significant wave height of 2.4 m.
A submerged pump would be mounted approximately halfway down the suction
pipe. Weekly production would be approximately 440,000 cu m, based on a
1144-hr work week. Maximum pumping distance would be 4.8 km. This type
of dredge could be used advantageously in thick, uncedented sand de-
posits within pumping distance of the project site. The need to recover
sand from deep water would increase the desirability of such a dredge.

52. The conventional self-propelled hopper dredge, especially
when fitted with swell-compensated dragarms, is well suited for the re-
covery of offshore sand and its transportation to the project site vic-
cinity. Moving the hopper dredge's cargo the last few thousand metres
to the beach, however, is still a problem when no sheltered waters are

* Adriaan Volker Baggermaatschappij B. V., personal communication,
Figure 21. Self-propelled dredge with swell-compensated suction pipe nearby. Methods used in the past include offshore dumping, pumpout through a mooring barge, and grounding of the hopper dredge. A recent beach nourishment project at Virginia Beach, Virginia,\textsuperscript{59} used a mooring barge tied to a self-elevating pier as the pumpout facility for a hopper dredge. A look at the petroleum industry's experience in loading and discharging oil tankers, however, suggests another method, based upon well-established technology: the use of a single-point mooring (SPM) system in conjunction with a hopper dredge with pumpout capabilities. SPM's are in widespread use in many parts of the world as an inexpensive means of mooring large oil tankers and providing pipeline facilities for loading and unloading. At least two installations are in use in New Zealand for loading iron sand slurry into ore carriers.\textsuperscript{60} A typical SPM system (Figure 22a) consists of a floating buoy moored by several anchor chains, with flexible hose leading from the buoy to a submarine pipeline. Floating flexible hose and mooring lines are connected to a swivel on top of the buoy. A ship approaches the buoy, ties to the mooring lines with or without the aid of a tender, picks up the floating flexible hose, and begins loading or discharging. While moored to the SPM, the ship is free to weathervane 360 deg. Casting off is basically...
a reversal of the mooring procedure. Another SPM design is shown in Figure 22b. Communications with several SPM manufacturers* have indicated that it could be feasible to design a portable SPM to be moved from project to project. Mooring and pumpout operations could be conducted in sea conditions up to and including those which would curtail dredging operations. A typical hopper dredge might require some modification to

![Figure 22a. Single-point mooring (SPM) design](image)

![Figure 22b. Single-point mooring (SPM) design](image)

**Figure 22. Single-point mooring (SPM) designs**

its lifting gear and discharge piping to adapt to such an operation. The total time required for a mooring and uncoupling cycle (not including pumpout time) would be approximately 1 hr. Such a system would be used best for a restoration project where large volumes of sand must be moved and where sheltered pumpout facilities are not available. The system's feasibility is increased if the borrow site is too far from the project site to allow direct pumping by another type of dredge.

53. One disadvantage of a hopper dredge, mentioned previously, is the loss of dredging time while transporting the dredged material from the dredging site to the pumpout site. The dredging system outlined in Reference 61 would be one way of overcoming this disadvantage while retaining the desirable features of a hopper dredge. The system (Figure 23) would consist of a trailing suction dredging unit and two hopper units. The hopper units would trail the dredging unit at a distance designed to minimize their relative motion, and would be loaded through two discharge pipes from the dredging unit's stern. The development of such a system would be more a matter of technique than equipment, since existing dredges and hopper barges could probably be used. The system's advantage would lie in areas where the transportation distance is too

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**Figure 23. Hopper barges loading from trailing suction dredge**
far for direct pumping to be feasible. It could also be used when two smaller projects which are being conducted simultaneously use the same sand source.

54. Interest in mining the ocean bottom for alluvial deposits such as gold or tin has led to the proposal of many new types of equipment to accomplish this mining. Some of this equipment can be classified as being of improved conventional design, and conceivably could be of use in offshore beach nourishment work. A typical example is the bucket ladder dredge proposed in Reference 62. The dredge would utilize 1.5-cu-m capacity buckets and be capable of digging to 45 m. The ladder would be supported by two hoist lines, each fitted with a swell-compensating mechanism. Anchoring and moving would be accomplished using wire rope. The dredge would be of essentially conventional design, with the addition of on-board treatment facilities for initial processing of alluvial ore. Annual output of the dredge is estimated at 12.6 million cubic metres.

55. Another design for an oceangoing bucket ladder dredge is described in Reference 63. In this concept (Figure 24), the upper end of
the ladder is supported by two hydropneumatic cylinders and limited in motion to a circular arc by use of two link bars. The ladder hoisting gear is fitted with a motion-compensating mechanism. This mechanism is also adjustable to allow variation of the ladder's digging force. It is claimed that, by thus supporting both ends of the ladder flexibly, the dredge is compensated for surge, heave, and pitch movement. Operational capabilities in waves up to 3 m are claimed by the designer.

56. A variation on the bucket ladder principle (Figure 25) would use buckets which drag across the bottom in a manner similar to a conventional dragline. The buckets would be attached to an "endless chain" which would loop over one end of the dredge and back down to the bottom via an idler frame. Since only a flexible catenary would be in contact with the bottom, a degree of swell compensation is inherent in the design. Since the dredge is proposed for offshore mining, a treatment plant is included.

57. The three mining dredge designs just discussed are similar in nature, and their possible uses in offshore beach nourishment projects are also alike. As mentioned previously, a bucket or drag-type dredge can either load its cargo into barges for transportation or deposit it into an onboard sump where it can be rehandled by pumps. For beach nourishment, the latter technique might prove economically uncompetitive with hydraulic dredges due to the added machinery required to perform essentially the same function of recovering and hydraulically transporting sand. Assuming that these mining dredges would be used to load barges, then, their principal advantages would lie in areas where direct pumping is unfeasible and where the ability to cut cemented sand or handle large rocks would be required. The need to recover sand from water depths beyond the capabilities of conventional hydraulic cutterhead dredges might also make the use of these dredges feasible.

58. Subcategory b, platforms, consists of proposed dredges wherein the body of the dredge is raised above water level by supports bearing on the ocean floor. This concept has been used successfully for years by the oil industry for offshore platforms. A dredge, however,
Figure 25. Catenary drag dredge
must possess some degree of self-mobility, thus adding another dimension to such a design.

59. The dredge described in Reference 65 is a good example of the platform design. Instead of using a square or triangular configuration for the dredging platform, an "L" shape was chosen to minimize weight (Figure 26). Three pairs of legs are used to provide support and mobility. When under tow, the legs are raised and the dredge floats, using the platform as a hull. At the dredging site, one leg from each pair is lowered to raise the platform above water. To move while dredging, the leg pairs are rotated and alternate legs in each pair lowered. The dredge can thus move at an estimated speed of 8.8 m/hr. Dredging would be accomplished using a cutterhead ladder attached to the platform itself. A later design of this dredge (Figure 27) shows a V-shaped hull with the ladder attached to the foot of a center leg.66 Also, the platform is designed to move with its legs "walking" in a stiltlike manner rather than rotating. The ladder would also support a submerged dredge pump. The platform is designed to be operational with an anchored floating pipeline in seas up to 3 m, and to remain onsite in seas up to 7 m. For loading barges or with an unanchored pipeline, the operational limit is 2-m seas. Maximum pumping distance would be 2 km, and maximum digging depth 25 m.

60. The platform dredge described in Reference 67 is designed for light work close to shore, although preliminary plans exist for a higher capacity, deeper water design.* The upper platform (Figure 28) is similar to a cutter suction dredge hull, with the addition of two screws for self-propulsion with the legs raised. Four legs are used, one at each corner of the hull, that terminate in a lower platform. Attached to this lower platform are eight hydraulically driven tractor wheels and the cutter ladder. In operation, the dredge would propel itself to the borrow site with its legs raised, then lower the legs and begin dredging. Mobility while dredging would be provided via the tractor wheels. The

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Figure 26. Walking platform dredge ("L" shape)
Figure 27. Walking platform dredge ("V" shape)
dredge is designed for use in 6 m of water, with a capacity of 150 cu m/hr through a 760-m discharge line.

61. Subcategory c, submersible dredges, seems to strike the fancy of many designers as being a solution to open-water dredging. As the name implies, these dredges are designed to operate completely submerged, in most cases resting on the ocean bottom. Some designs would require umbilical cables to a surface ship or shore, thus making the dredging system subject to surface conditions.

62. One design for an unmanned submersible dredge is described in general terms in Reference 68. Although intended for deepwater foundation construction, some of its features might prove advantageous to submersible beach nourishment dredges. The dredge would rest on the bottom, move on tracks, and excavate material using a cutterhead. Power would be supplied from the surface by a coaxial cable. TV cameras and acoustic positioning techniques would be used to monitor the dredge's position. The dredge would have a minimum excavating capacity of 19 cu m/hr and would be designed to run for 600 hr without maintenance.

63. Another possible type of submersible dredge (Figure 29) would consist of a long cylindrical tube with two pairs of crawler tracks at each end, a dredging ladder in the middle, and an articulated, inclined
Figure 29. Underwater dredge (with crawler tracks)

The central portion of the cylindrical tube would contain the dredge crew, controls, and diesel machinery. The outer ends of the tube would house ballast tanks. The snorkel would allow ventilation of the tube and would house an elevator to transport personnel and supplies to and from the surface. The top of the snorkel would bend and project approximately vertically out of the water to a height of 10 m. That part of the snorkel out of the water would support landing platforms and a small crane. The dredge would not require a surface power supply. Fuel and water would be supplied to the tube via pipelines in the snorkel. Since the dredge is designed for cutting underwater trenches, the excavated material would be discharged underwater through pipes at either end of the cylindrical tube. Steering would be accomplished using a remote sonar buoy and dredge-mounted hydrophones.

64. One of the major differences between submersible and conventional dredges is the type of hull or vehicle used to carry the dredging equipment. Since many proposed submersible dredges incorporate a bottom-crawling vehicle, developments in this area are of prime importance to the realization of these dredge designs. Reference 70 describes two prototype unmanned underwater bulldozers, one for shallow water and the other for deep water. The shallow-water machine (Figure 30) consists of
a bulldozer connected to a surface power barge via an S-shaped, articulated arm. The bulldozer has two tanks which can be filled with air to float it or adjust its weight on the bottom. The power barge contains a hydraulic power unit, air compressor, and bulldozer controls. A sign pole projecting above the surface is used to indicate the attitude of the bulldozer and its blade. Hydraulic fluid and compressed air are supplied to the bulldozer along the articulated arm. Maximum working depth is 5 m, and maximum bulldozer speed is 3 km/hr.

65. The deepwater bulldozer (Figure 31) is designed for operation in 5 to 60 m of water. Like the shallow-water machine, it is driven by hydraulic motors. However, in this case, the hydraulic pump is mounted in the bulldozer itself and is powered via an electric umbilical cable from a surface support ship. The 150-m-long, 74-mm-thick cable also carries control and information signals to and from the surface. The position of the machine underwater is monitored acoustically and displayed on an X-Y recorder on the surface ship. Ground contours in front of the bulldozer are monitored by a transducer attached to the machine's front. The attitude of the machine is determined using a vertical gyro and a gyro compass. Like the shallow-water model, the deepwater machine can be floated with integral buoyancy tanks. A deepwater bulldozer designed by another company* is similar in most respects, except that it must be raised and lowered by a surface crane. Maximum speed of both

* Komatsu, Ltd., personal communication, 1973, Tokyo, Japan.
machines is the same as that of the shallow-water bulldozer, 3 km/hr.

66. Reference 63 briefly describes a proposed submersible dredge (Figure 32) in the shape of a truss frame with two spuds at one end, a bucket wheel at the other, and two pairs of swiveling crawler tracks in between. The dredge is designed for use in 90 to 180 m of water, and includes buoyancy tanks for surfacing and descending. A pump would be used to move material excavated by the bucket wheel. The dredge would be operated by remote control from a surface ship.

67. A conceptual design is discussed in Reference 61 involving a true submarine dredge, i.e., one which operates without resting on the ocean bottom. Two modes of operation for such a dredge are discussed. One would have the dredge tethered to a fixed point such as a tower or monobuoy by a flexible pipeline. The fixed point could also incorporate a booster station for moving the slurry longer distances. The other mode of operation would use submarine hoppers which would be loaded underwater by the dredge.

68. A preliminary design for an offshore iron-ore-sand mining
dredge is briefly described in Reference 71. The machine (Figure 33) would consist of a T-shaped unit resting on the bottom, connected by an articulated shaft and a flexible pipeline to a surface ship which would provide power, control, and preliminary processing of the iron ore sand. The T-shaped unit would have a cutterhead and pump at one end and spuds at each end of the cross member. The entire unit could be carried in the well of the catamaran surface ship. The dredge is designed for work in 18 to 43 m of water.

69. The submersible dredge described in Reference 72 is envisioned by the designer as part of a family of underwater crawler vehicles. In the dredge configuration (Figure 34), the vehicle would consist of a main hull with a snorkel, dredging arm, and discharge pipe connected to it. Four spherical wheels would drive two crawler treads and would also act as buoyancy tanks. Diesel engines breathing through the snorkel would drive the remotely controlled vehicle.
Figure 33. Iron-ore-sand underwater mining dredge
Figure 34. Underwater crawler dredge
70. Semisubmersibles, the fourth subcategory of proposed equipment, incorporate those dredges designed to be relatively insensitive to wave action by virtue of having only a small portion of their hull located near the surface. This approach to the problem of providing a stable working platform is being used extensively by the major oil companies in the design of their floating drilling rigs (see Reference 73 for a summary of the latest designs). FLIP (Figure 35), a well-known semisubmersible in the shape of a large spar buoy, has been in use for several years as an oceanographic research platform. Therefore, the designers of semisubmersible dredges can draw to a large degree on established technology and proven concepts.

71. One design for a nonself-propelled semisubmersible dredge is described in Reference 66. The dredge (Figure 36) resembles a large Erlenmeyer flask floating upright with the neck protruding above water.

Figure 35. Research platform FLIP
Figure 36. Semisubmersible plain suction dredge

A plain suction pipe is connected to the dredge's base, supported by a boom on the "neck" of the craft. Pumping and power machinery is located in the base, while the control house sits on the top of the neck. Using variable ballast tanks, the dredge can vary its draft from between 4.5 and 25 m. It would normally pump the dredged material through a pipeline, possibly using other dredges of the same design as booster stations.

72. Reference 47 includes a description of a semisubmersible dredge considerably different from the one previously discussed. This dredge (Figure 37) would use a twin pontoon hull floating below the
water surface, with trusses rising above water to support the superstructure. Pumps and propulsion machinery would be located in the pontoons, and two trailing suction pipes per pontoon would be used to recover sand. Screws would be located at each end of the craft, so that it could change direction without turning around. The craft could operate either as a trailing suction or a stationary dredge. In either case, it would load self-propelled barges from the well between pontoons. The dredge may or may not incorporate a sand storage bin on top of the truss framework.
73. References 63 and 75 include artists' concepts of semisubmersible dredges. In both instances, the dredge hull would be of the submerged pontoon type, with columns supporting an above-water platform. The dredge in Reference 63 is intended for tin ore mining, and would use a bucket ladder as the recovery mechanism (Figure 38). The vessel described in Reference 75 was inspired by an offshore drill rig and would use a cutter suction system to mine deep ocean minerals.

74. The final subcategory, miscellaneous, of proposed offshore beach nourishment equipment naturally contains widely diverse designs. As in previous sections, some of these designs were not necessarily intended for beach nourishment use. They are presented, however, to show the range of possibilities which can be considered in searching for an optimum system.

75. Reference 76 describes a proposed system for rehandling sand carried by a hopper dredge or barge (Figure 39). The hopper dredge or barge would dump sand onto a jet pump field emplaced on the bottom directly offshore of the beach. Shore-based pumps would supply drive water through a submerged pipeline to the jet pumps, which would then pump a sand-water slurry back to shore through a submerged discharge line. If deposited in sufficiently deep water, the sand dumped onto the jet pumps would be relatively immune to wave action, thus allowing the stockpiling of sand for future use. The shore-based drive-water pumps would be mobile, with the idea of serving several locations along a coast. Since jet pumps do not produce high discharge heads, a design for an underwater jet pump booster is included to be used in cases where the jet pump field must be located a substantial distance offshore. Such a system might have applications for continuous or periodic nourishment in areas where sufficient water depths exist near shore to allow hopper dredge unloading.

76. The next system to be considered is designed for use in free-flowing, thick sand deposits relatively close to shore. The sand recovery mechanism (Figure 40) is a probe consisting of two vertical pipes joined to a mixing box at the bottom. A hydraulically driven roller crusher is mounted above the mixing box opening, and a jetting
Figure 38. Semisubmersible bucket ladder dredge
Figure 39. Jet pump rehandler

Figure 40. Sand recovery probe
nozzle emanates from the bottom of the box. In use, the probe is jetted into a sand deposit by divers, using a previously emplaced vertical pipe as a guide; once buried, suction is applied through a flexible hose to one of the probe's pipes, the other being open to admit seawater. Sand feeds by gravity into the mixing box, where the incoming seawater creates a slurry that is carried up the flexible hose to a surface boat; from the boat, the slurry is pumped to shore. The roller crusher serves to grind up coral and shell fragments to prevent their clogging the mixing box opening. As sand is pumped, an ever-deepening crater forms around the probe. When the bottom of the crater reaches the bottom of the probe, pumping stops and the probe is jetted deeper into the deposit. Pumping then resumes, and this method of operation continues until the bottom of the sand deposit is reached. This system may have applications for small projects in areas where deep pockets of sand exist close to shore, and where divers can operate successfully.

77. The system briefly described in Reference 78 is unusual in that it would not only use a new piece of equipment but also a new source of beach nourishment material. The material, called aragonite, is currently being mined from underwater deposits in the Bahamas.79 It consists of sand-sized, rounded particles formed by the precipitation of calcium carbonate around a nucleus particle such as a shell fragment. The new equipment (Figure 41) is intended to be a means of unloading dewatered aragonite from a carrier vessel and pumping it to shore. It comprises a large, cylindrical capsule containing two cutting jets and a hydraulically powered slurry pump. The capsule is lowered by a crane into the ship's hold and buries itself in the aragonite using the cutting

Figure 41. Aragonite unloader
jets. It then begins pumping, using the cutting jets to create an aragonite slurry. Since the aragonite is loaded dry into the carrier, some such means of rewatering is necessary prior to pumping it onto a beach. Such a system (including the use of aragonite as the beach material) might be applicable to areas where suitable deposits of sand do not exist, and which are located within economic hauling distance of the aragonite mining operation.

78. As previously discussed, the major problem encountered when using conventional dredging equipment offshore is its usually poor ability to work under wave action. Most attempts at improving this situation have been directed toward modification or redesign of the dredge itself. An alternative approach, however, is to provide a means of sheltering the dredge from wave action. Mobile breakwaters of the design type referred to as passive floating may supply this shelter, although technology in this area is by no means well established. Passive floating breakwaters act to reduce wave energy by absorbing and/or reflecting it, without the use of external energy sources. Several examples of such designs are given in References 80 and 82, and an example design is shown in Figure 42. They range from floating bundles of old automobile tires to more complicated structures using steel trusses or perforated plates. Many of the current designs perform best when their width (dimension normal to wave front) is in the vicinity of one-half the incident wavelength or greater. Obviously, then, the damping of longer period waves may require a large floating structure. In addition, the analysis of stresses within the breakwater and forces exerted on the mooring system is a complicated problem. The application of mobile breakwaters to offshore dredging, therefore, may be in areas subject to short-period waves and where frequent movement of the breakwater is not required. Such a situation might exist when a dredge is used to rehandle material offshore, or when a thick sand deposit is mined with a stationary dredge.

79. The dredging system described in Reference 83 could be classified either as "submersible" or "miscellaneous." The heart of this system (Figure 43) is a submersible miner containing a slurry pump,
Figure 42. Floating breakwater
ballast tanks, water jet pumps, underwater lights, and television camera. In use, the miner would pump sand to shore via a semisubmerged discharge line while tethered to a support barge anchored in the vicinity. The support barge would supply compressed air to drive the miner’s pumps and to fill the buoyancy tanks. It would also serve as a base for monitoring and controlling operation of the miner. Movement of the miner would be accomplished using water jets on either side. Such a system might be employed in low-volume beach nourishment projects where the sand source is relatively close to shore.

80. Several types of movable pipelines for transporting sand from the borrow site to shore were discussed in the section on existing equipment. Unfortunately, the type best suited for offshore work, the flexible floating pipeline, is also the most expensive to purchase. A compromise between reliability and cost, however, may be achieved through use of a semisubmerged pipeline. Basically, such a design would consist
of steel pipe sections suspended a certain distance under the surface from buoys. The sections would be joined by flexible rubber hoses to form a pipeline. The use of spar-type buoys* to support the pipeline would reduce its susceptibility to wave action (Figure 44). The pipeline could be floated at the surface by tying the spar buoys flat against it, and would become semisubmerged by simply undoing one end of each buoy. It might also be possible to provide a reliable connection between a semisubmerged and submerged pipeline by gradually increasing the suspension depth of the semisubmerged pipe sections. The semisubmerged pipeline would have applications in almost any situation requiring a movable pipeline.

![Figure 44. Semisubmerged pipeline](image)

81. The last two systems to be considered under the "miscellaneous" heading are related in that they are both designed specifically for the deep-sea recovery of manganese nodules. Although neither system as presented would be usable in a beach nourishment project, their principles of operation are unique enough to warrant description in this report.

82. Reference 84 describes a means of mechanically dredging at great depths using a continuous bucket line (Figure 45). This is basically a long, continuous moving loop of rope with scraper buckets

Figure 45. Deepwater bucket line dredge
attached at intervals. The loop passes over the stern of a surface vessel, down to the ocean floor, along the floor where minerals are scraped into the buckets, and up to the surface at the ship's bow. The buckets are detached from the line at the bow, unloaded, and reattached at the stern. During dredging operations, the ship moves at right angles to the loop plane so that a segment of the ocean floor is swept by the bucket line.

83. The dredging apparatus described in Reference 45 is designed to operate on the principle of the previously discussed air lift (Figure 46). Instead of using compressed air to lower the specific gravity in the suction pipe, however, a recyclable light medium with a specific gravity less than that of water (e.g. kerosene or hollow glass spheres) is employed. The system would consist of a scraper to be dragged along the ocean bottom, a mixing chamber into which the light medium is injected, and a duct containing the light medium and discharge piping. The mixing chamber and scraper are connected by a suction pipe, and the duct terminates at a surface ship. There, the light medium is separated and pumped back to the mixing chamber, and the dredged material is collected.
84. The range of existing and proposed equipment described thus far, although extensive, is by no means complete. The dredging industry is noted for its lack of literature, and the topic of offshore dredging is no exception. Although some promising designs may have been omitted, it is believed that most types of existing and proposed equipment have been given at least token representation. The problem now becomes one of assembling some possible systems for offshore beach nourishment by using equipment types already discussed.

Equipment selection

85. Some sort of equipment selection process must begin at this point to limit the discussion of systems to those with the best chances of success. For reasons previously discussed, such a selection will unavoidably contain a large dose of subjectivity. The category of submersible dredges, for example, will be dropped from further consideration for several nonquantifiable, but nonetheless sound, reasons:

a. The successful application of submersible dredges would amount to a technological quantum jump in a traditionally conservative U. S. industry which has little offshore experience.

b. Many submersible designs require surface support, thereby limiting a system to surface conditions.

c. Maintenance, control, and manning of a submersible dredge present many problems not found in surface ships.

86. Also, some mechanical dredge types such as the bucket ladder will not be carried further, since:

a. Their advantages over hydraulic dredges (ability to dig hard material and recover large rock-size particles) are not necessarily needed for beach nourishment.

b. Except for grab-type dredges, the U. S. dredging industry uses few mechanical dredges (approximately 92 percent of U. S.-owned mechanical dredges can be classified as grab dredges, compared with 18 percent for The Netherlands, which has the next largest dredging fleet85).

c. Mechanical dredges are limited mostly to loading hopper barges as a means of transport.
87. Elimination of other equipment is done on a more individual basis. In the case of proposed equipment, for example, those designs which are obviously little more than artists’ concepts have been dropped. Pieces of existing equipment which have been proven unseaworthy, such as the conventional hydraulic cutterhead dredge and the ball-joint pontoon pipeline, have been likewise omitted. Equipment types surviving this initial trimming have been arranged into the systems described herein and summarized schematically in Plate 1. Plate 1 is arranged in the manner of a logic network to show how several pieces of equipment may be combined into many different systems, each with its own characteristics. A system is "constructed" by starting at the left with either an existing or proposed dredge, and proceeding to the right along the network lines until the "beach" block is reached. In addition to describing systems, the network also indicates areas where equipment designs are scarce, such as the "proposed rehandler" and "proposed transport" categories.

Classification

88. A review of the engineering considerations involved in selecting optimum offshore beach nourishment systems will suggest several ways of categorizing these systems. They might be classed according to production capacity: can the system perform large restoration projects, or is it suited only for continuous-type nourishment? Mobility of the system could be used as a means of classification: can the system operate over a large borrow area; can it seek shelter some distance away when storms threaten? Systems might also be grouped according to their limiting operational wave climate.

89. While such classification criteria are valid and useful, they would not necessarily divide the offshore nourishment systems into groupings descriptive of particular system types. Also, groupings which use quantitative criteria such as production capacity or limiting wave climate would be approximate at best when applied to proposed equipment. For the purposes of this report, therefore, the offshore beach nourishment systems will be grouped according to whether or not the
system would rehandle* the dredged sand.

90. Such a classification is both descriptive of system types and immune to quantitative inaccuracies. Systems will also be subgrouped into those using all existing equipment and those incorporating some proposed equipment.

**Nonrehandling**

91. Looking at nonrehandling existing systems first, the selection is somewhat limited. A swell-compensated plain suction hydraulic dredge pumping to shore through a flexible floating pipeline might be used where the borrow deposit is thick and close to the project area and where mechanical cutting is not required to recover the sand. A shallow-draft hopper dredge with horizontally sliding bottom doors would constitute a system in itself, if the nearshore topography would allow it to ground close to the beach and dump its cargo. For small volume projects, a shore-based mechanical scraper could recover and transport sand to shore, provided the sand could be recovered far enough from shore so as not to undermine the existing beach profile.86

92. Several systems are possible under the category of nonrehandling: proposed. Where mechanical cutting action is required, a swell-compensated cutterhead dredge could be used as the prime mover. A mobile elevated platform could also employ a cutterhead and remain on station during nonoperational weather. Either of these could use a flexible floating or semisubmerged pipeline as a means of transporting sand, or else a length of such pipeline for mobility, connected to a submerged pipeline. Provided loading techniques could be worked out, the elevated platform might be used to load shallow-draft barges which would dump their cargo close to the beach. Where mechanical cutting is not needed, a swell-compensated plain suction dredge could be used with any of the previously described pipeline configurations. If sufficient water depth exists, the plain suction dredge could be of a semisubmersible design which, because of its relative stability, might be used to

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* Rehandling is defined as the use of more than one means of transport in moving a unit of sand from the borrow site to the project.
load barges as well. Where mobility in the borrow area is required, some sort of trailing suction dredge is indicated. A semisubmersible trailing suction dredge might be used to load hopper barges for dumping close to shore.

Rehandling

93. The category of rehandling systems could contain literally hundreds of possibilities, since the number of times sand can be rehandled is unlimited. Obviously, however, multiple rehandlings will usually prove uneconomical. Therefore, the possible rehandling systems discussed in this report will be restricted to one rehandling operation each.

94. The first group under the heading of rehandling systems is that composed of existing equipment. The hopper dredge is the only existing dredge mover which is both suited for offshore operation and amenable to rehandling. If sheltered waters exist near the project, the hopper dredge can dock and pump its cargo through shore-based pipelines; or it can dump its cargo in a calm area where it would be rehandled by a conventional hydraulic dredge. If the distance from the project area to the borrow area is great and no sheltered waters exist, the hopper dredge might dump offshore for rehandling by a swell-compensated plain suction dredge connected to a flexible floating pipeline.

95. The final and largest group of possible offshore nourishment systems consists of rehandling systems using proposed equipment. A hopper dredge could be used to recover sand and dump it offshore, where it could be rehandled by an elevated platform dredge or a jet pump field. Hopper barges loaded in the borrow area by an elevated platform, semisubmersible trailing suction, or semisubmersible plain suction dredge could also be used to feed either of the above-described rehandlers as well as a swell-compensated plain suction dredge. A conventional hydraulic dredge might be used as an offshore rehandler if effective floating breakwaters were available to shelter it. Another rehandling system using a hopper dredge would consist of the hopper dredge pumping to shore via an offshore single-point mooring and a submerged pipeline.
96. Thus far, the concept of beach nourishment has been broadly discussed. Nourishment projects have been divided into three categories:
   a. Restorative
   b. Periodic
   c. Continuous

97. Examples have been given of each type of project. The engineering considerations involved in choosing optimum systems for nourishment from offshore sources have been outlined. Existing and proposed equipment for use in such systems has been classified as follows:

I. Existing
   A. Equipment for recovering sand from the source
      1. Mechanical
      2. Hydraulic
      3. Nonconventional
   B. Equipment to transport sand from the source area to the project
      1. Transporting vessels
      2. Pipelines
      3. Pipeline connections
      4. Floating boosters

II. Proposed
   A. Improved conventional
   B. Platform
   C. Submersible
   D. Semisubmersible
   E. Miscellaneous

98. Individual pieces of equipment have been described under each class and possible uses given. Finally, types of offshore systems have been categorized:

I. Nonrehandling
   A. Existing
   B. Proposed
II. Rehandling
   A. Existing
   B. Proposed

Possible systems have been constructed on paper for each category using selected pieces of equipment.

99. The next logical step toward a final product would be to decide which of these "paper" systems warrants further investigation. However, such a step requires knowledge of the characteristics and requirements of future U. S. offshore nourishment projects. Will most have borrow areas close to the project? What amount of sand will be required? What is the yearly wave climate in the borrow area? At present, such knowledge does not exist in a coherent form directed toward the problem of offshore beach nourishment. Much of the basic data, however, is available from sources such as National Oceanic and Atmospheric Administration publications, the National Shoreline Study, and the Inner Continental Shelf Sediment and Structure Study.

100. The next activity of this project, therefore, will be the initiation of a study to compile and correlate the information necessary to give a quantifiable picture of the future U. S. offshore nourishment situation. Such information should, among other things, allow prediction of the relative need for various system types and equipment characteristics. In addition to its immediate application in this investigation, such a study will be of value to groups interested in coastal zone management, offshore dredging and mining, and other related activities.
REFERENCES


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Table 1
Summary of Engineering Considerations and Their Effects on Nourishment Systems

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<td>System production capacity</td>
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<td>Environmental restrictions in borrow area</td>
<td>Digging characteristics and turbidity generation of recovery equipment</td>
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<td>(b) Borrow and project site characteristics</td>
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<td>Water depth at borrow site</td>
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<td>(c) Borrow deposit characteristics</td>
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<td>Size frequency distribution of borrow versus beach sand</td>
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Schematic of Offshore Beach Nourishment Systems