CHAPTER 58

CRATER-SINK SAND TRANSFER SYSTEM

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ABSTRACT

A sand transfer system that requires no surface impounding area and that can be installed and operated at low cost is proposed The system consists of a hydraulic jet assembly operating from the bottom of a sand crater A jet pump and suction mouth are located at the lowest point of a crater-like depression dredged into the sea floor The crater acts as a gravity-fed sink for sand and other cohesionless material, thus serving the dual purpose of a mechanism for collecting sand and a sub-surface impounding area for the accumulation of sand

INTRODUCTION

The large volumes of sand transported by waves and currents in the nearshore zone has always presented a serious problem to the coastal engineer (Johnson, 1957) The problem is particularly serious with engineering structures associated with the entrances to harbors and coastal lagoons Coastal structures that interrupt the longshore transport of sand produce local areas of accretion on the up-coast side of the structures and corresponding areas of erosion on the down-coast side In time, both the accretion and the erosion become problems, whose common solutions require that the accreted material be bypassed to the area of erosion Over the years various procedures have been developed to handle the bypassing of sand around coastal structures, (Eaton, 1951, Watts, 1966, Tornberg, 1968)

All of these bypassing procedures require the construction of "impounding" or storage areas where the sand accumulates until its volume is sufficient to warrant bypassing by suction dredge or other means Impounding requires that the longshore transport of sand be intercepted before it reaches the entrance channel This is usually accomplished by building a suitable structure, which commonly takes one of the forms illustrated in Figure 1 All of these procedures involve expensive construction and maintenance Further, to attain maximum efficiency the impounding areas must be large, thus occupying valuable coastal area

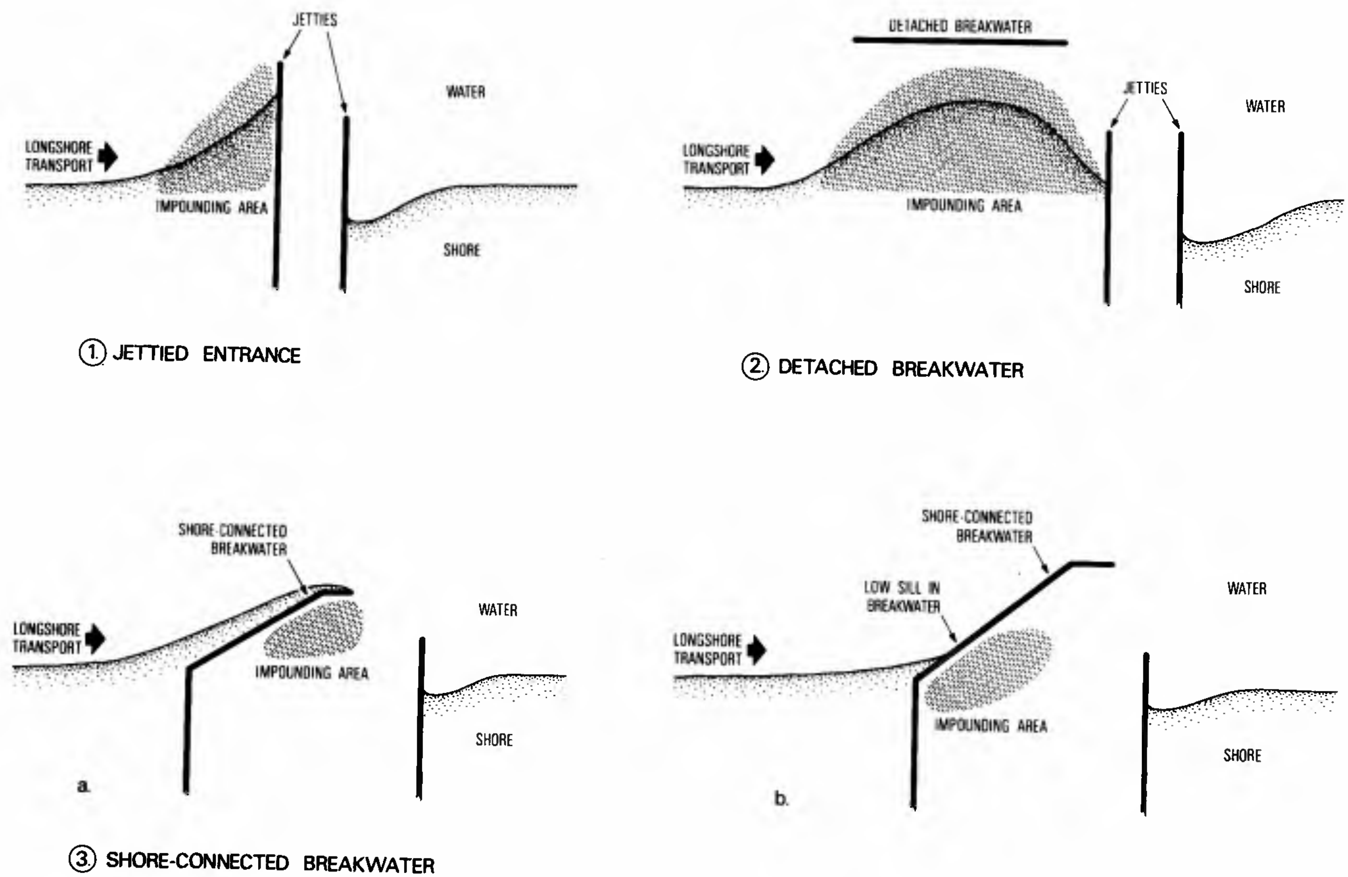

Figure 1. Schematic diagrams of the types of impounding areas associated with entrances to harbors and coastal lagoons (after Watts, 1966). Prototype examples include: (1) South Lake Worth Inlet, Florida (Watts, 1963); (2) Channel Islands Harbor, and Port Hueneme, California (Herron and Harris, 1966); (3a) Santa Barbara, California (Wiegel, 1959); and, (3b) Masonboro Inlet, North Carolina (Magnuson and Rayner, 1966).

Considerations of the overall budget of sand in the nearshore areas of the world show that the problem has a more basic aspect than just that of sand bypassing Beach sand has become an important natural resource that is diminishing in quantity at an alarming rate This has come about because man has progressively decreased the supply of sand to the beaches by damming rivers and has interrupted its longshore movement with coastal structures On the other hand, the loss of sand from the nearshore zone, either down submarine canyons or by other means, remains at a high rate (Inman and Frautschy, 1966) Various procedures, such as dredging sand from the continental shelf (Taney, 1965) and pumping sand from coastal impoundment areas (Herron and Harris, 1962) have been suggested for supplying sand to undernourished beaches

The increasing need for sand bypass systems and for beach nourishment systems makes it apparent that the development of different, more efficient sand transfer systems is an urgent necessity if we are to retain our coastal zone resources Accordingly, a sand transfer system that requires no surface impounding area and that can be installed and operated at low cost is proposed

CRATER-SINK SAND TRANSFER SYSTEM

The crater-sink sand transfer system consists of a hydraulic jet assembly operating from the bottom of a sand crater The hydraulic jet assembly consists of a suction mouth, a jet pump, a drive-water pipe, and, a delivery pipe that transports the sand-water mixture away from the crater site (Figure 2) Since the suction mouth is located at the lowest point of a crater-like depression in the sea floor, the crater acts as a gravity-fed sink for sand and other cohesionless material Sand transported to the perimeter of the crater will cascade down the sides of the crater to the suction mouth where it becomes available for transfer Thus, the crater-sink serves the dual purpose of a mechanism for collecting sand and a sub-surface impounding area for the accumulation of sand When located in the entrances to harbors and inlets, it provides the greatest depth of water in the entrance channel where it is needed Once installed the system is stationary and the only moving parts are in the drive-water pump When required, the jet pump assemblage and delivery pipe can be floated to the surface for maintenance, as discussed in the section on installation

HYDRAULIC JET ASSEMBLY

Recent developments in jet pump technology now make it practical to use hydraulically driven jet pumps to move sand through pipelines The excessive wear rates caused by the highly abrasive sand-water mixtures have been markedly reduced in recently designed pumps The new designs have resulted from experiments (1) on the optimum shape and angle for the nozzle entry into the throat of the Venturi section of the pump (Figure 3), and, (2) with various types of resistant linings for the

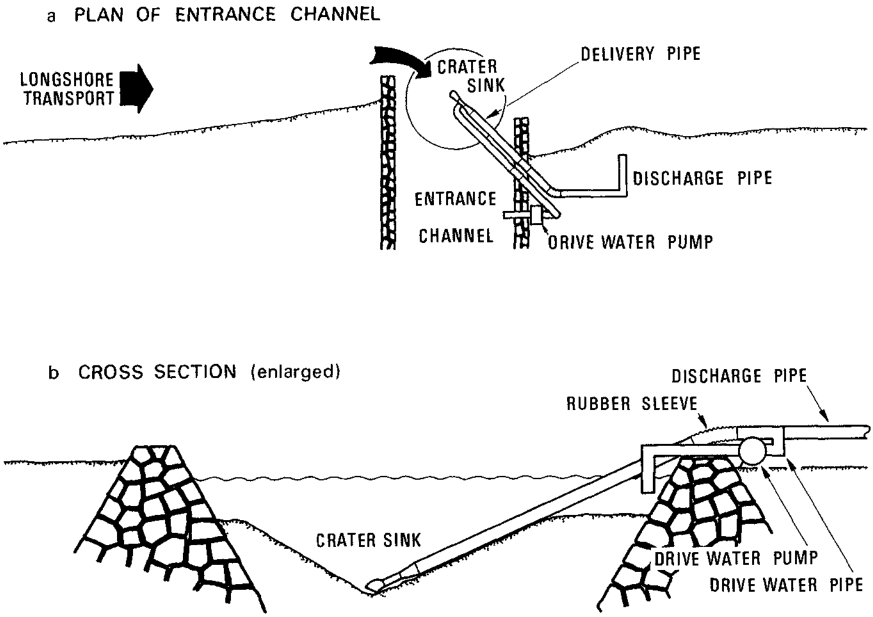

Figure 2 Schematic diagram of crater-sink sand transfer system when used to bypass sand across the entrance to a harbor or lagoon

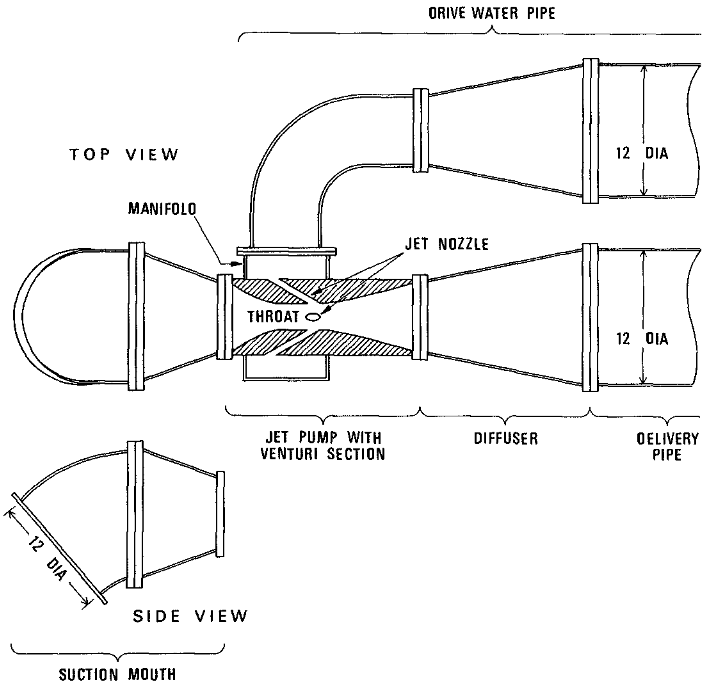

Figure 3 Schematic diagram of the hydraulic jet assembly

Venturi throat of the pump (D M Frazier, 1967, W G Fraser, unpublished manuscript, J V Barker, 1969)

Improved jet pumps of this type have been in use for several years as suction booster pumps behind the cutter head on suction dredges Experience by various users */ indicates that the wear life of a jet pump, before requiring new plastic linings, is now measured in millions of cubic yards rather than hundreds of thousands of cubic yards The basic rate of pumping for a jet pump driving a 12-inch ID delivery pipe would be in excess of one million cubic yards of sand per year This includes approximately 25% down-time for maintenance

The hydraulic jet assembly driving the crater-sink sand transfer system consists of a suction mouth, jet pump, diffuser, and delivery pipe The jet pump consists of a cylindrical cast steel Venturi section which is fitted with a series of peripheral nozzles (Figure 3) The nozzles are inclined towards the centerline of the Venturi throat, and are driven by water supplied to the cylindrical manifold surrounding the Venturi section Drive water is supplied to the manifold through a separate pipe which is fed by a water pump

The delivery pipe is coupled to the jet pump by a diffuser which increases the diameter of the Venturi section to that of the delivery pipe The delivery pipe brings the sand to the landing pipe, where it may be discharged at the shoreline through a short discharge pipe If the sand is to be discharged at a more distant point, then a booster pump driving an extended discharge line must also be installed, as shown in Figure 7

INSTALLATION AND CHARACTERISTICS OF THE CRATER-SINK

The initial installation can be made in several ways If the thickness of cohesionless sand is sufficient to provide a crater of the desired size, the crater can be excavated by the hydraulic jet assembly The assembly could be floated and towed to the site, where it could then be flooded with water and used to excavate itself into place The crater will then be developed as the delivery pipe is extended from a handling barge or ship (Figure 4a)

If the thickness of cohesionless sand above a consolidated soil horizon is thin, then it will be necessary to excavate a crater of the desired size, using conventional methods such as a suction dredge with a rotary cutter head Once the crater is formed then the jet pump and discharge pipe can be floated over the site, flooded with water and the rig set into position (Figure 4b)

*/ For example, jet pumps have been used by General Construction Co , Portland, Oregon (personal communication), Pacific Dredging Co , Long Beach, Calif (personal communication), Western-Pacific Dredging Co , Portland, Oregon, Utah Dredging Corp , San Francisco, Calif, and, the U S Corps of Engineers, Portland District (Fraser, unpublished manuscript) Also, a jet pump system for offshore sources of sand has been recommended by Govatos and Zandi (1969)

In the absence of currents, the crater walls would normally stand at the static angle of repose of the sand which is about 30 degrees Thus, the minimum size of the crater would be that occurring for static conditions, where the diameter would be approximately four times its depth, and the volume of the crater would equal about 4 2 times the cube of its depth Therefore, a 50 foot deep crater would have a minimum circular perimeter with a diameter of about 200 feet, and a volume of 20,000 yd^3, while a 100 foot deep crater would have a minimum diameter of 400 feet and a volume of 155,000 yd^3

The dynamic effects of currents flowing across the sand crater would result in crater slopes that are less than the static angle of repose, and thus increase the periphery and the volume of the crater Also, the effective collecting periphery of the crater-sink would be extended by the sand transported to the rim of the crater by currents The effect of currents and wave action on crater shape is not clearly understood and should receive further study

The successful functioning of the crater-sink concept requires that the crater be sited so as to intercept the longshore transport of sand Entrance channels tend to migrate along the coast in the direction of the longshore transport as well as in an on-offshore direction with changing wave and current conditions (Inman, 1950, p 15) Thus, the construction of a short up-coast jetty to stabilize the location of the "transport path" of the littoral drift is important in siting the crater-sink (Figure 2) The principal function of a down-coast structure would be the protection of the site for the drive-water pump and the landing and discharge pipes

Excavation of the Crater Sink with the Jet Unit

The equipment for this operation is shown schematically in Figure 4a and includes a suitable barge with ground tackle and lifting gear and a drive-water pump The jet pump end of the assembly of delivery and drive-water pipes is suspended from a barge in such a way as to provide both vertical control and horizontal control of the suction mouth The delivery pipe is fitted with pontoons which support the delivery pipe for transporting the sand away from the crater site

After the crater is excavated the pipeline and jet assembly are moved to the beach where the pontoons are removed, the pipelines are lengthened to suit the installation and stability tanks are attached The shore ends of the drive-water pipe and delivery pipe are blanked off at the landing pipe and air is pumped into both pipes Since there is less bouyancy at the jet pump end of the pipes, the suction mouth will always float lower than the rest of the pipe, thus effectively preventing a large loss of air through the suction mouth When the assembly has been floated into the correct position air is vented at the landing pipe position and the jet pump end of the assembly begins to descend, the descent rate being controlled by the residual air in the pipes After sinking into position, the discharge pipe is connected to the shore end of the landing pipe, and the drive-water pipe is connected to the drive-water line from the drive-water pump Raising of the hydraulic jet assembly is carried out in the reverse procedure as described above

EXTENSION OF CRATER-SINK BY FLUIDIZATION

It would appear that the perimeter of the crater-sink could be effectively extended in any desired direction by fluidizing the sand bed A sand body tends to behave as a fluid when the fluid pressure in the pore spaces at any level are equal to or greater than the immersed weight of sand above this level This technique is widely used in industry for the transport and mixing of granular-fluid media (Flood and Lee, 1968) and could be used to extend the effective perimeter of a crater-sink system without requiring an increase in the depth or width of the crater It would appear that this could be accomplished by installing a length of pipe, fitted with jet holes, that extended from the crater-sink to some distant shoal If the pipe were laid along the bottom with jet holes in the "down-position", then pumping water at a high rate through the pipe would activate the jets and cause the pipe to bury into the sand bed Once in place, a reduced pumping rate could be employed that would fluidize the sand above the pipe, without causing it to jet further into the bed As long as the bottom of the crater is deeper than the shoal the fluidized layers of sand, under the influence of gravity, will flow towards the crater-sink (Figure 5)

The extension of a crater-sink by long fluidization units appears to be particularly applicable to long, narrow entrance channels, which commonly result in the formation of shoals outside of the entrance (Figure 6) This application is essentially the reverse of that suggested by Hagyard, et al (1969), which would have employed a one mile long fluidization unit located off Westport Harbor, New Zealand, to transport sand from the entrance channel into deeper water However, the experiments performed by Hagyard, et al (1968) on fluidizing velocities, depth of burial of pipe, and the shape of the fluidized zone above the pipe, should also apply to the crater-sink concept In fact, since the installation proposed here would involve relatively short fluidization units operating over relatively steep slopes and feeding continuous sand sinks, its application should be less critical than that suggested by Hagyard, et al However, the technology for fluidizing natural sand beds has not been perfected, and it is quite apparent that both applications require further study before committing them to prototype conditions (Wilson and Mudie, in preparation)

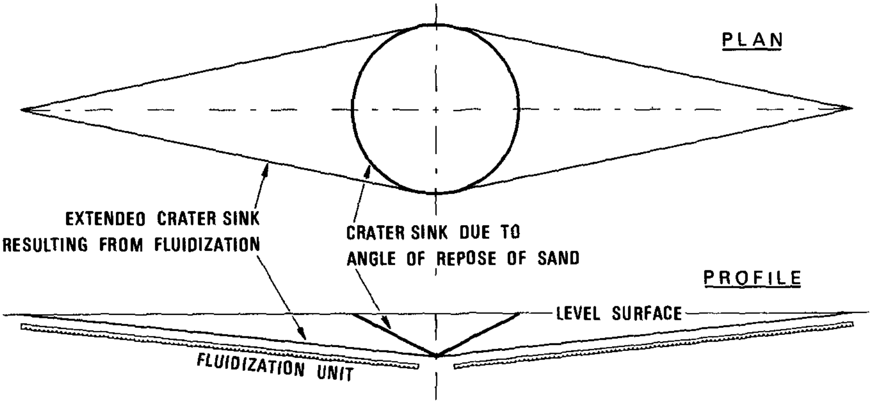

Figure 5 Extension of the periphery of the crater-sink using two fluidization units (Refer to Figure 6)

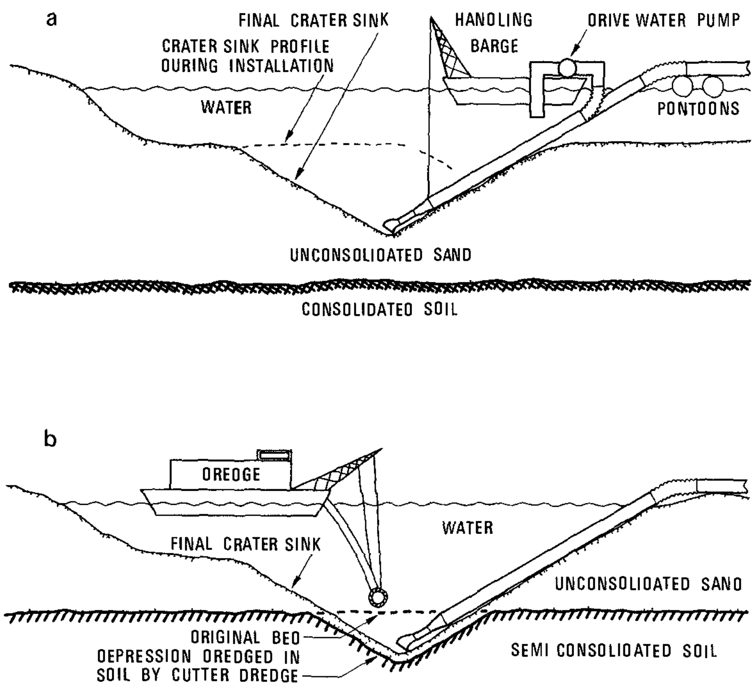

Figure 4 Schematic diagram showing the various methods of constructing the crater-sink (1) direct installation from a barge or boat using the hydraulic jet assembly as a dredge and (b) excavation of a crater into semi-consolidated soil u-ing conventional suction dredge with a rotary cutter head

CHARACTERISTICS OF A TYPICAL INSTALLATION AT A SANDY INLET

As stated previously, additional research is warranted before the crater-sink concept and its extension by fluidization is employed in the field However, it is instructive to consider the characteristics of such an installation as based on present understanding

Consider the crater-sink sand transfer system that would be required to maintain an entrance channel 20 feet deep and 500 feet wide through an inlet where the net longshore transport is known to be 400,000 cubic yards per year Assume that there are occasional reversals in the direction of transport, amounting to about 100,000 cubic yards, so that the system must be capable of pumping in excess of 500,000 cubic yards per year Further, assume that there is a tendency for a bar to form offshore from the inlet, so that the perimeter of the crater-sink must be extended for 1000 feet offshore from the end of the up-coast jetty This situation is analogous to that shown schematically in Figure 6 and listed in Table 1, and is a fairly common one along the sandy coastlines of the world

For an inlet of this type a hydraulic jet assembly pumping from the bottom of a 50 foot deep crater would probably provide sufficient perimeter for the basic crater The minimum width of the crater would be about 200 feet as determined by the static angle of repose of the sand, while the dynamic width in the presence of waves and currents would probably be about 300 feet as shown in Figure 6 A vertical lift of 70 feet and a horizontal delivery distance of about 400 feet is within the capacity of existing jet pumps If the basic crater can be extended seaward by installation of a 1000 foot long fluidization unit it would then be possible to extend and maintain the channel through the central portion of the offshore bar as shown in Figure 6

The use of turn pipes and rubber sleeves permits accomodation of a variety of bottom profiles, while providing lateral stiffness and maintaining alignment Life of the equipment can be extended by exchanging sand delivery and drive-water pipes when the former wear thin

The operating schedule for the jet pump would depend upon demand For example, the pump could be turned on every 24 hours and would then operate until the sand fill in the crater had been removed During times of low wave activity it would operate perhaps one or two hours per day, while during times of pronounced longshore transport it could operate 24 hours per day

Table 1 Characteristics of crater-sink sand transfer system (extended by fluidization) when used to bypass sand around an inlet and entrance channel Sand is to be discharged directly on the beach face near the landing pipe as shown schematically in Figure 6

ENTRANCE CHANNEL AND INLET			
water depth			20 ft
channel width			500 ft
distance to offshore bar			700 ft
longshore transport rate of sand, net			400,000 yds^3/yr
longshore transport rate reversed direction			100,000 yds^3/yr
total required sand pumping capacity			500,000 yds^3/yr
CRATER-SINK			
crater depth			50 ft
water depth at center of crater			70 ft
crater width - minimum (still water)			200 ft
crater width - maximum with waves and currents			300 ft
crater length - minimum			1,200 ft
crater length - maximum			1,300 ft
HYDRAULIC JET ASSEMBLY			
jet pump*/	Venturi throat diameter		10 in
	nozzles - number		4
	nozzles - diameter		1 in
	rated flow capacity	approx	5,500 gpm (12 ft^3/sec) total flow

Table 1 (Continued)

drive-water pump**/	flow capacity	2,200 gpm (5 ft^3/sec) 250 horsepower
delivery pipe	length (jet pump to landing pipe	300 ft
	diameter I D	12 in
elevation of discharge point above mean water level		10 ft

*/ For example, jet pump model 12 in, manufactured by Pacific Coast Engineering Co , Alameda, California

**/ For example 2200 gpm at 150 psi, 250 horsepower, electric driven water pump, manufactured by Byron-Jackson Pump Co , Los Angeles, California

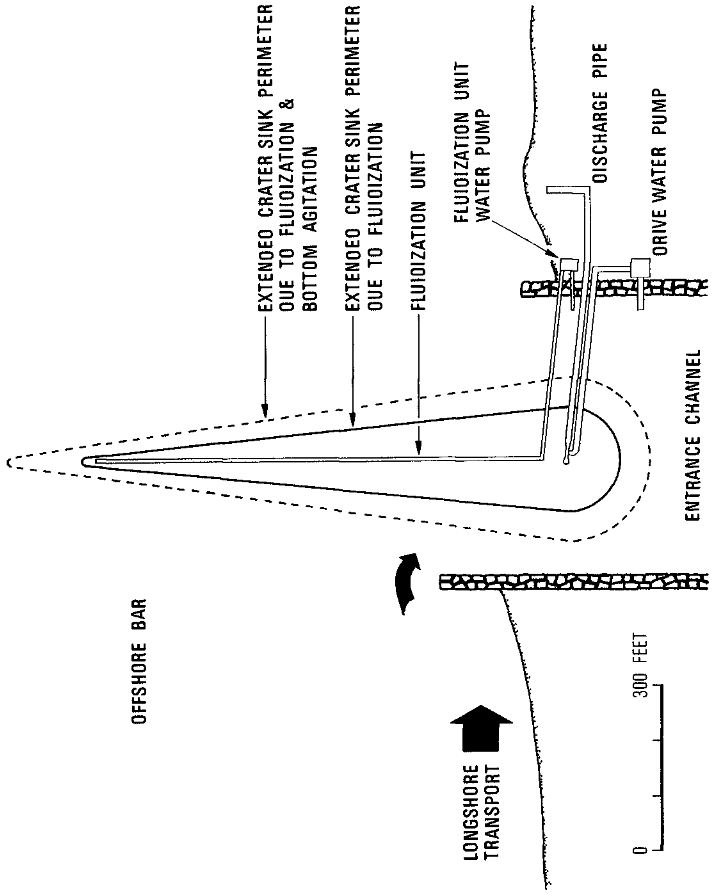

Figure 6 Schematic diagram of a fluidized crater-sink employed for sand bypassing at an inlet with offshore bar

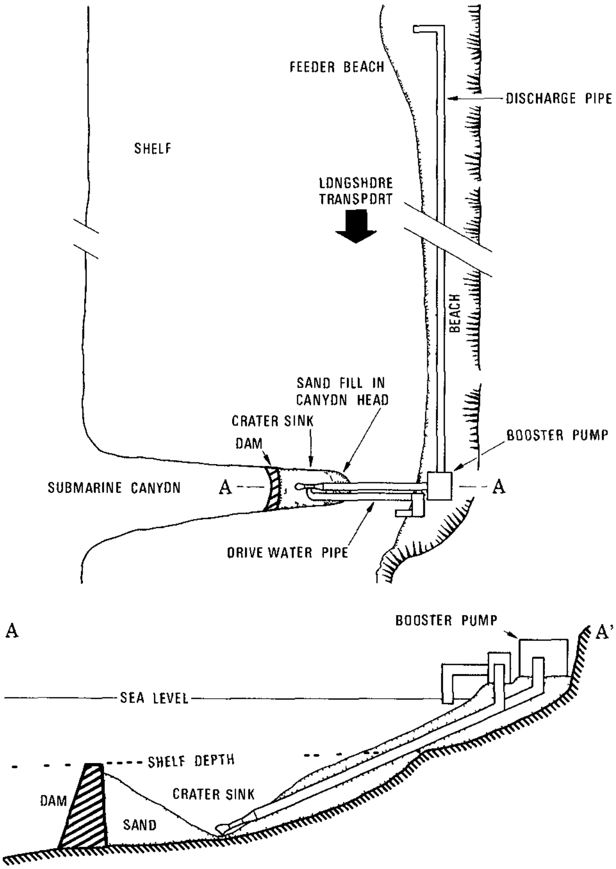

Figure 7 Schematic diagram of the crater-sink sand transfer system used to recycle sand in a littoral cell with longshore transport Sand trapped by a sub-surface dam across the head of a submarine canyon is pumped up-coast to a feeder beach where it again becomes available for longshore transport

CONCLUSIONS

The advantages of the crater-sink sand transfer system over conventional dredging appear to include (a) simple, inexpensive equipment requiring a minimal amount of labor, (b) lower operating costs, (c) no obstruction to navigation, (d) elimination of the up-coast sand impounding area, and, (e) the ability to operate throughout the year, thus providing a continuous bypass operation which maintains the natural drift rates along the coast and eliminates the down-coast zone of erosion

Once perfected, it would appear that a crater-sink sand transfer system would have a variety of coastal and inland applications In addition to its use at sandy inlets (Figures 2 and 6), it would appear to have potential for pumping sediment from dams that have intercepted the supply of sand formerly brought to the coast by streams and rivers Also, the sand transfer system could be used to recycle sand to feeder beaches on a coast with littoral drift Sand trapped on the down-coast end of a beach could be pumped to feeder beaches along the up-coast portions of the beach where it again becomes available for longshore transport as illustrated schematically in Figure 7

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REFERENCES

Angas, W M , 1960, "Shark River inlet sand bypassing project", Jour Waterways and Harbors Div , Amer Soc Civil Engin , vol 86, WW 3 paper 2599, p 29-47

Barker, J V , 1969, "The PACECO jet stream system", World Dredging and Marine Construction, June p 28-30

Eaton, R W , 1950, "Littoral processes on sandy coasts", Proc First Conf on Coastal Engin , Council on Wave Research, the Engineering Foundation, p 40-54

Flood, H W and B S Lee, 1968, "Fluidization", Scientific American, vol 219, no 1, p 94-104

Fraser, W G , "Development of a dredge jet pump", Pacific Coast Engineering Company, 5 pp (unpublished)

Frazier, D M , 1967, "New dredging techniques using an annular jet", Proc of WODCON, World Dredging Conf , p 115-131

Govatos, G and I Zandi, 1969, "Beach nourishment from offshore sources", Shore and Beach, vol 37, no 2, p 40-49

Hagyard, T , I A Gilmour, W D Mottram, 1969, "A proposal to remove sand bars by fluidization", New Zealand Jour Sci , vol 12, p 851-64

Herron, W J Jr , and R L Harris, 1966, "Littoral bypassing and beach restoration in the vicinity of Port Hueneme, Calif", Proc Tenth Conf Coastal Engin p 651-675

Inman, D L , 1950, "Beach study in the vicinity of Mugu Lagoon, Calif", Beach Erosion Board, Corps of Engin , Technical Memo 14, 47 pp

Inman, D L and J D Frautschy, 1966, "Littoral processes and the development of shorelines", Coastal Engineering, Santa Barbara Specialty Conference, Amer Soc Civil Engin p 511-36

Johnson, J W , 1956, "Dynamics of nearshore sediment movement", Amer Assoc Petrol Geologists Bull , vol 40, p 2211-2232

Johnson, J W , 1957, "The littoral drift problem at shoreline harbors", Jour Waterways and Harbors Div , Amer Soc Civil Engin , vol 83, WW1, paper 1211, 37 pp

Magnusom, N C and A C Rayner, 1966, "Stabilization of Masonboro Inlet", Shore and Beach, vol 34, no 2, p 36-41

Taney, N E , 1965, "A vanishing resource found anew", Shore and Beach, vol 33, no 1, p 22-26

Tornberg, G F , 1968, "Sand bypassing systems", Shore and Beach, vol 36, no 2, p 27-33

Watts, G M , 1966, "Trends in sand transfer systems", Coastal Engin Santa Barbara Specialty Conf , Amer Soc Civil Engin , p 799-804

Watts, G M , 1953, "Study of sand movement at South Lake Worth Inlet, Florida", Beach Erosion Board, Corps of Engineers, Technical Memo, 42, 24 pp

Weigel, R L , 1959, "Sand bypassing at Santa Barbara, Calif", Jour Waterways and Harbors Div , Amer Soc Civil Engin , WW 2 paper 2066, 30 pp

Wilson, C R and J D Mudie (in preparation), "Comments on the removal of sand bars by fluidization", New Zealand Jour of Science