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Beach Nourishment—Improved Economy Through Better Profiling and Backpassing from Offshore Sources

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ABSTRACT

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Recent professional literature on artificial nourishment of beaches includes a number of papers criticizing nourishment as inefficient and not long lasting. Part of the criticism, admittedly for any objective and experienced professional, is well taken and reasoned by practical experiences. Losses associated with normal beach nourishment procedures are mainly caused by too fine material and by the lack of proper consideration to profile geometry. This paper discusses various options to improve beach fill stability by proper "profiling" that means nourishment on the beach and on the nearshore offshore bottom simultaneously and to the extent available equipment permits. It also considers backpassing to the shore by the introduction of non-conventional equipment available or in the development stage.

ADDITIONAL KEY WORDS: *Beach erosion, profile nourishment, beach fill stability, nearshore profile, offshore currents, dredging, hopper dredge.*

INTRODUCTION

Losses associated with normal beach nourishment procedures are mainly caused by too much fine material in the borrow sand and lack of proper consideration of the profile geometry.

This article discusses various options to improve beach fill stability by "profile nourishment," *i.e.* nourishment on the beach and nearshore offshore bottom to the extent needed or as available equipment permits. It also considers "backpassing" to shore by the introduction of non-conventional equipment which is already available or being developed.

PROFILE NOURISHMENT

Considerations of the geometry of the combined beach and nearshore profile was overlooked until fairly recently. Use of split hull barges changed that situation. A pioneering work was done by the U.S. Army Corps of Engineers when the "Currituck" was launched (SCHWARTZ and MUSIALOWSKI, 1977).

Offshore dumping of fill, *e.g.* derived from maintenance operations in tidal navigation inlets, stabilized part of the offshore profile. Beach stability was improved partly because some of the sand dumped offshore was washed up on the beach and partly because the shoals generated offered better wave protection. The USACE (Wilmington District) and the Waterways Experiment Station (Control Engineering Research Center, Vicksburg, Mississippi) developed a numerical model to study beach profile changes related to dispersion of dredged materials disposed in the nearshore zone (unpublished report by the USACE, Wilmington District, on "Feasibility Study, Dredging and Nearshore Disposal Plan, Oregon Inlet, North Carolina," 1983).

One of the main problems with conventional artificial nourishment has been the rapid loss of fills on the beach. This circumstance has often been used to discredit beach nourishment as a whole. One reason for the rapid loss lies in the unnatural "forced" steepness of the beach fill (BRUUN, 1988). Another cause is the very high content of fine-grained material that is not suitable for beach fills.

Most materials of less than 0.15 mm wash out rapidly. Part of it is lost in the handling procedures, though most stays in the fill and is subject to rapid wash-outs. Overfill (R_A) seems to be the only answer to this problem (USACE, 1984). It is largely avoided in situations where the fill is derived from offshore sources of relatively coarse material which was deposited by

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currents, or was glacial meltwater sand as found off some northern European shores, mainly the North Sea as mentioned below.

Innumerable examples from the field have demonstrated the normal trend of a gradual decrease of grain size with depth—until a certain point. Deepwater currents, however, may change the normal pattern, causing the appearance of migrating sand waves on the bottom (BRUUN, 1954). Such waves may contain coarser sand or coarse sand deposited at a time when the water table was lower than today. Coarse sand may also have washed out from rivers or by glacial meltwater streams.

An example of the action by offshore currents is found on the continental shelf off Sydney, Australia. To cite from *Sediment Features and Processes of the Sydney Continental Shelf* (Public Works Department, New South Wales, Coastal Branch, Technical Memo, No. 85/2, December, 1985):

> From the shoreline, sea bed sediment gradually becomes finer offshore. From medium sands in the surf zone with a typical median grain size (d_{50}) of 0.35 mm, the sand grain size reduces to a d_{50} of 0.18 mm in 14 m depth.
>
> These finer sands generally continue out to depths of 25–30 m. From 30 m out to about 60 m, a diverse suite of sediments are found. They range from fine sand to coarse sand and gravel. Deeper than 60 m, fine sands with some silt content predominate. Shell contents are highly variable but are generally highest near areas of exposed reefs.

An example of glacial river deposits occurs in the coarse sands found off the Danish North Sea coast. These deposits are excellent for beach nourishment because grain sizes occur in the range 0.5–1 mm. Also found off the Dutch coast, they have been used for nourishment at Schreveningen.

The obvious answer to better overall profile stability is profile nourishment. Theoretical and practical aspects of profile nourishment are dealt with by BRUUN (1988).

Interest in profile nourishment is still on the increase because:

(a) It allows the use of two, perhaps three, different kinds of material. Material which is not well suited for the beach because it is too small, but is available in large quantities at a lower cost, may be used for offshore nourishment of the profile.

(b) As shown by a limited number of numerical model results (KRAUS and LARSSON, 1988) and as experienced in practice, profile nourishment gives a more stable profile than just beach nourishment. This means that the rapid initial losses which almost always occur with normal beach nourishment procedures largely can be avoided by proper design and execution of profile nourishment.

(c) If the material and equipment are available for profile nourishment, combined beach and offshore nourishment may be more economic than just beach nourishment. The U.S., still, is short of shallow draft dredgers for such operations.

(d) If the material available is so uniform that it is impossible to tune grain sizes to depth ranges in the natural profile, the new profile can still be better shaped towards a more stable profile, by the spoiling (dumping) process, particularly if the material is coarser than the natural beach/bottom material (CHRISTIANSEN, 1977).

Table 1 shows the various procedures of profile nourishment combining offshore and onshore nourishment, with materials corresponding to or coarser than the natural material—or by just one grain size. For each location materials finer than any of the natural materials should *not* be used—or only be used as "sublayers."

The most sophisticated, and at the same time the most economical method in large scale operations is outlined in Case 1, which concerns offshore nourishment by split-hull dredge barge and beach nourishment by a hydraulic pipeline method. Split-hull dumping is shown in Figure 1 together with "over-the-bow" pumping. Figure 2 shows discharging of sand through a permanent pipeline buried in the sea bed leading to the beach, as installed on the Danish North Sea coast south of Thyboron. The material, as

Table 1. *Profile nourishment under various assumptions.*

BORROW MATERIAL	GRAIN SIZES A and B A > B UNIT PRICES a and b a > b		
EQUIPMENT	ON (onshore — hydraulic pipeline) OFF (offshore — pumpout, bottom door, split hull)		
CASE ONE	EXAMPLES	CASE THREE	EXAMPLES
A (a) and B (b)	DENMARK AUSTRALIA	A (a)	
ON and OFF	In Denmark permanent terminal installed in bottom on 9 m depth	ON and OFF	USA. DENMARK, AUSTRALIA, HOLLAND
A dumped by ON B dumped by OFF		A (beach) by ON B (nearshore) by OFF	Netherland Antilles
CASE TWO	EXAMPLES	CASE FOUR	
A (a) and B (B)	DENMARK, AUSTRALIA, HOLLAND	A (a) by ON	
Two ON by Y-method		A (beach) planned for Hilton Head Island, South Carolina MSL and up, profiling by dumping process and nature. Nourishment extends eg. to minus 2 meters mlw.	
nearshore (B) beach (A)		A (beach) MLW ±, profiling on beach by earth-moving equipment. Nourishment extends eg. to minus 3 meters mlw. Example: Queensland, Australia	

In all cases higher stability is obtained because:
Bead load transport away from beach ~ slope angle or
Suspended load transport away from beach ~ d E(x) / dx or ~ slope angle

It is not a sound design principle to count on rapid losses of material from the beach designed for maximum stability!
Concentration on just grain sizes for solely beach nourishment has become an obsolete design principle.

mentioned above, is glacial meltwater-sand which is coarser than the beach sand and excellent for nourishment (BRUUN, 1988). More information is given in the following section on "Backpassing." The price is about \$3.50 per m^3 or \$2.50 per cubic yard, a highly competitive price, not easily obtainable by pipeline dredging.

Case 2 assumes two different types of material spoiled partly on the beach and partly offshore through the same pipe, or offshore by split hull equipment leaving a gap of 100 to 300 m for self-filling. The mathematical model for diffusion of such fill mentioned earlier checked by field results show how this process takes place and its advantages (USACE, Wilmington). The development may be compared to a stockpile on the beach, but in the offshore case the spreading or diffusion is much more pronounced in directions x-y-z. BRUUN (1988) explains the advantages obtained with this procedure. In Australia, the average price for beach and offshore dumping was as little as \$1.20 per cubic yard (1985). [In 1989 the average price was \$1.00 per cubic yard.]

Case 3 has only one type of material which is placed on the beach and nearshore bottom by two different types of equipment which could be a hydraulic pipeline dredge or a hopper dredge with pump-out capability to the beach. Offshore it could be a split-hull dredge barge. Danish practices are described by BRUUN (1988, 1989) and by LAUSTRUP (1988).

Case 4 uses the same material, which is dumped on the beach in its full width, *e.g.* as in Figure 3 showing the Dutch "quick-coupling method" (CUR, 1987) to widen the beach and make a gentler slope, or simply by additional profiling by a scraper pan or a large bulldozer. This is particularly important if borrow sand is "on the fine side." With such procedures fill may reach 3–4 m depth below MLW (mean low water) so that at least "an approach to true profile nourishment" is achieved. The advantage, as proven by comprehensive field experiences (Denmark, Queensland, Australia) as well as in the laboratory (KRAUS and LARSSON, 1989) and described in great detail by BRUUN (1989, vol. 2) is a better overall beach stability and storm tide protection.

BACKPASSING

Backpassing by definition is the transfer of material "back to shore" by a mechanism which

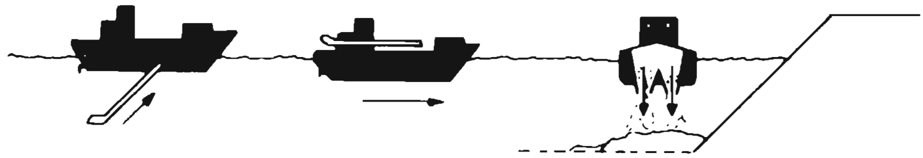

Figure 1(a). Direct dumping in the nearshore zone with hopper dredgers or hopper barges (CUR, Holland, 1987).

Figure 1(b). Trailing suction hopper dredger pumping through nozzle placed in the bow (CUR, Holland, 1987; see also Bruun, 1988).

Figure 1(c). Dredge discharging over the bow, Danish North Coast (DANENA Dredging Co.).

moves material from offshore to the beach or to the nearshore bottom (BRUUN, 1988, 1989). It differs from bypassing which is movement of material past a littoral drift barrier and downdrift to a shore which suffers from erosion due to a littoral drift barrier (BRUUN, 1978, 1989).

Figure 2(a). Hopper dredger with pump-out capability discharges material through offshore bottom terminal and permanent pipeline in the bottom. The Danish North Sea Coast, Coastal Directorate, 1985–1989.

Backpassing is made possible through the use of different kinds of equipment ranging from scraper pans from the lower part of the beach itself to hydraulic transfer equipment pumping material to the shore from deeper waters. Various methods are mentioned in CUR (1987), profiling by CHRISTIANSEN (1977) and by BRUUN (1989, Vol. 2).

The following discussion focuses on long-range planning for beach stability by nourishment based on more frequent nourishment cycles, *e.g.* one to three years and transfer of material to the shore through permanently installed backpassing stations. As explained by BRUUN (1988), such a station has now been in operation on the Danish North Sea coast for 5 years with great success by pump-out through a buoy connected to a bottom pipe terminal. Because weather caused problems with the hose link between the dredger and the buoy station, the actual year round operation time is limited to perhaps 3 or 4 months. Such a station could be more functional, particularly on exposed shores, if it was run by a combination of split hull barges dumping material in a large dredge trap to be emptied *e.g.* by a spudded or "all weather" jack-up dredge barge carrying fluidization or jetcrater pumps to pipes in the trap and a booster pump for pumping of material to shore and along the shore. The dredge barge may then move from station to station along an eroding shore of considerable length or along several separated shores with transfer stations, *e.g.* for every mile (1,600 m) or 2 miles (3,200 m). Left alone the dredged traps will also be able to accumulate material brought in by waves, by bottom creep or by longshore currents. This material could also be pumped to shore if grain sizes did not deviate too much from the beach sand. If it is smaller it can still be used in the nearshore or as a sublayer for sand of compatible size to beach material or larger sands secured from offshore deposits, *e.g.* in inlet shoals.

Figure 2(b). The land-end of the shore-pipe under construction (1985). (Danish Coastal Directorate).

A "historic case" of backpassing using mechanical means is discussed by BRUUN (1967) for Jupiter Island on the Atlantic coast of Florida. Reference here is to the nearshore zone inside 6 m (20 ft) depth where a long-range dragline was used. Investigations included comprehensive tracer tests on the movement of materials around the offshore bottom area.

Hydraulic methods of "backpassing" are different for less exposed and exposed shores. For less exposed shores, the most practical and economical procedure is almost always pumping to shore from an offshore source of considerable magnitude by a hydraulic pipeline dredge. The problem, however, is not only the availability of quantities of suitable materials within limits but the safety of the pipeline which may be subjected to considerable and variable forces by waves and/or currents. The pipeline may be carried to shore over anchored floats or it may be submerged and anchored in the bottom which limits the risks of damage by stronger waves and currents. It may also be mainly floating but submerged through the surf zone. In all cases either navigation or bottom life and fisheries are disturbed.

On exposed shores, hopper dredgers are needed to bring the material close to the shore or beach. Offshore (profile) dumping may be by split hull dredge or by dredge pumping over the bow as shown in Figures 1a, b and c (Danish North Sea Coast). Here European and Ameri-

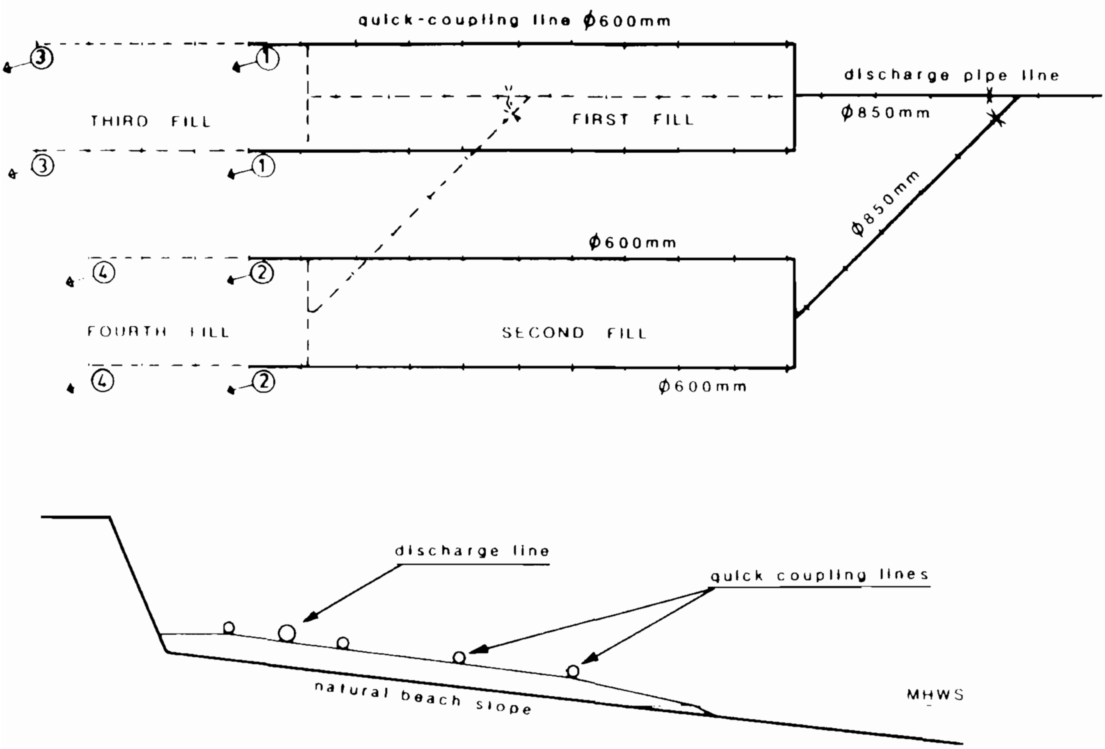

Figure 3. The Dutch quick-coupling method, CUR, Holland, 1987. (a). Quick-coupling System.

can practices differ. They are partly related to nearshore profile steepness and partly to the availability of equipment. The shallowest (minimum draft loaded) U.S. dredge of split hull type has a loaded draft of 11 ft (3.4 m). The corresponding European figure is 8 ft (2.5 m). On most shores of the United States, dredges must stay outside 1,000 ft (300 m) for dumping. On many European shores dumping is allowed 30–60 m (100–200 ft) from the shoreline which may be at the high tide line. This is due to the relatively higher steepness caused by coarser material.

Pumping over the bow has the same advantages as seen from Figure 1c. The dredge discharges perpendicular to shore thereby gradually decreasing its draft. With a draft of about 14 ft when fully loaded, it will finally (by unloading) reach a draft of about 7 ft. Adding 3 ft for possible wave action, the draft in the final stage needs to be 10 ft depth or 3 m. As such it is able to discharge as close to shore as shown in Figure 1c, where "trimming" also adds to "the success." Most remarkable the price in Denmark is about $2 per cubic meter ($1.50 per cubic yard).

Onshore dumping depends upon a pipeline which may be floating but often is submerged. Only at one place in the world have they, at this time (1989), had the "courage" of establishing a permanent pipeline in the bottom extending from a bottom intake terminal to the beach. That is on the very rough Danish North Sea coast. Figure 2a shows a hopper dredge discharging through a 20 inch (0.5 m) pipeline buried in the bottom with its permanent intake located about 600 meters from shore at 7–8 m depth. Figure 2b is the beach-part of the pipeline as shown in the picture taken during construction in 1984. All such pipeline connections have a "moveable link" between the dredge and the pipeline, usually a hose of special design features. This weak point sometimes causes problems due to wave action. A recent (1988) example is the repeated breakdowns during the beach fill operation at Amelia Island on the

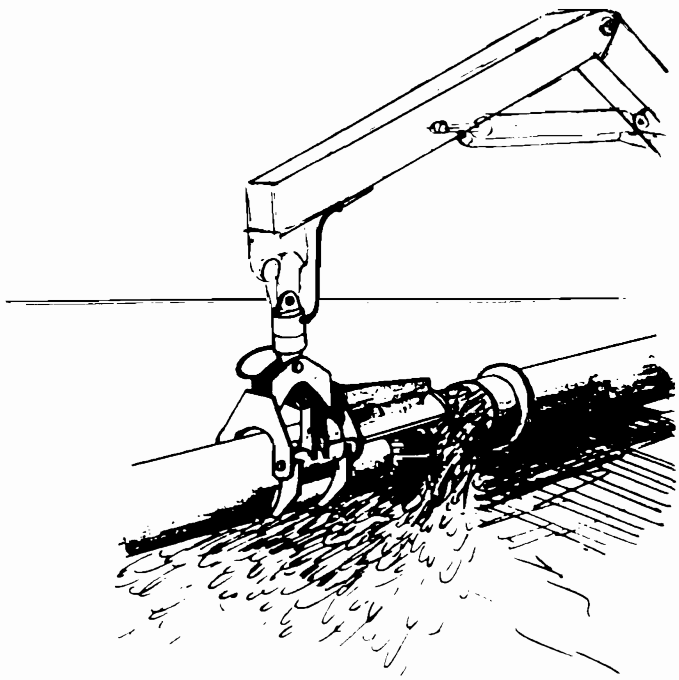

Figure 3(b). Hydraulic crane for quick-coupling system.

northeast coast of Florida. This does not mean that such projects are not successful under less exposed conditions, but operations may have to be limited to a few or perhaps a 6–8 month period of relatively calm seas and this slows down the entire operation and increases the costs of nourishment. The obvious question is, "How can this weak link be improved?" One way is by an improved link-design, as *e.g.* the "Able Design Floats," mentioned in a brief note on "Ancillary Aids for the Dredging Industry," published by "Dredging and Port Construction" (September 1988) or as described by DETTE (1988). Another possibility is a combination of a split hull dredge or dredge-barge which dumps the material at a fixed installation which could be a spudded (relatively milder conditions) or rather a jack-up or semi-submersible barge. See *e.g.* van DRIMMELEN and GOOSENS (1977), BRUUN (1981, 1989—Chapter 10. The barge carries pumps and a boom-intake. Many jack-up barges of 150–250 m^2 area and 21 m jack-up is presently (1989) available from the offshore industry (*e.g.* OTIS, New Orleans). The viability of such a solution, however, depends upon its capacity, efficiency and economy. Those kinds of installations are found at typical fixed bypassing plants as *e.g.* the Lake Worth and the South Lake Worth Inlets in Florida (BRUUN, 1981, 1989—Chapter 9). Such plants unfortunately have to shut down operations during even milder wave actions (about 0.5 m or 2 ft). Furthermore, their boom length is limited to about 15 meters (50 ft) or less. Consequently, their trap size is small, hardly ever exceeding 1,500 m^3 (2,000 yd^3). Such "small" traps will fill quickly during a storm thereby rendering it useless. For efficient and economical operations traps need to be much larger, *e.g.* 18,000 m^3 (25,000 yd^3), corresponding to an approximate one thirtieth of the annual drift in one direction at a U.S. eastern seaboard tidal inlet. For efficient and steady operation, even during storm conditions, pump and pipe equipment must have no parts which can easily be moved and twisted by wave and/or current action.

Figure 4 is a schematic layout of an arrangement combining a splithull dredge with a jack-up or platform dredge which carries equipment

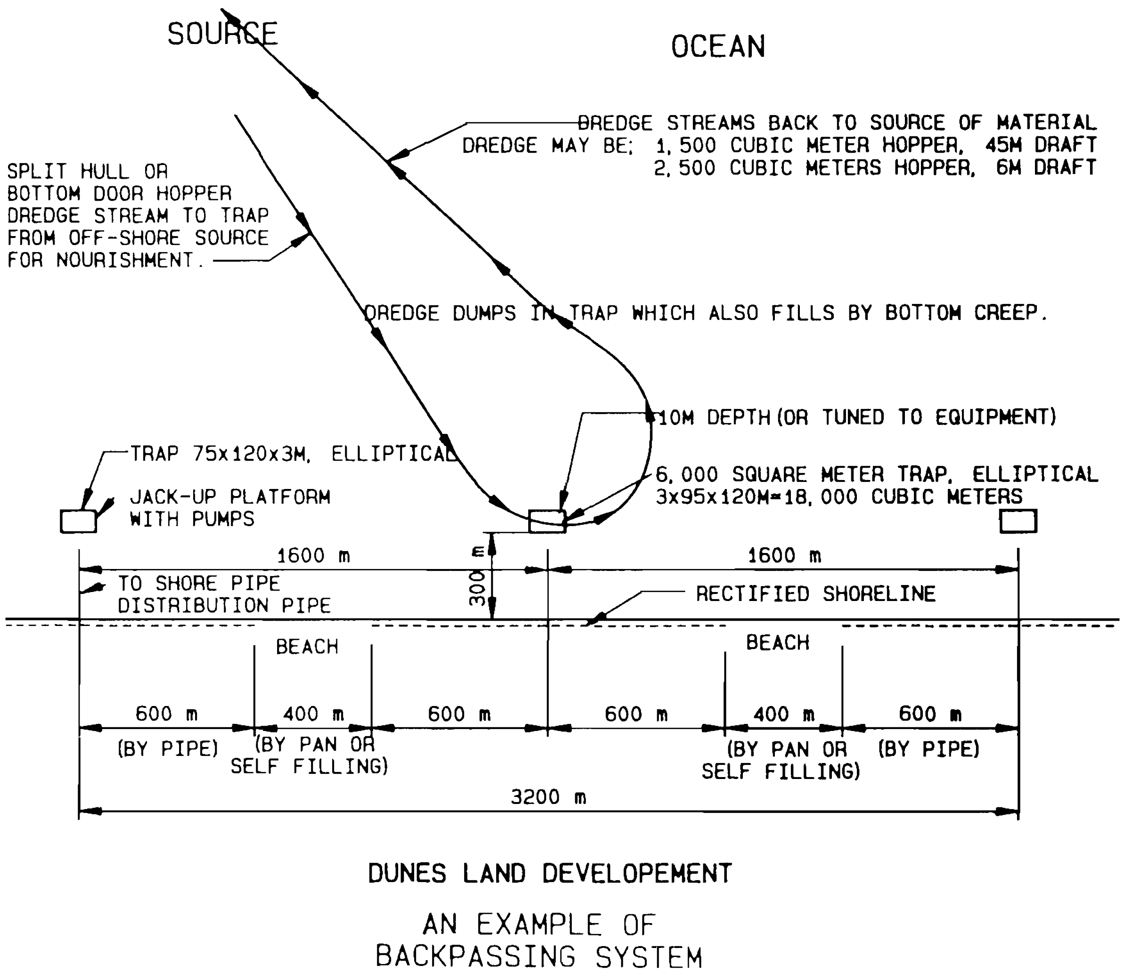

Figure 4. Backpassing system including split-hull dredger and jack-up platform terminal carrying pumps for dredging of mammoth trap discharge to shore through permanent pipeline in the bottom. Platform may be spudded or of jack-up type.

for fluidization or jet crater pumps combined with a normal booster pump to bring the material to shore and probably also alongshore. The difference between the two pumps lies in the pressures. A fluidization pump needs about 10 kg/cm^2 (150 lbs/sq in). A booster only about 7 kg/cm^2 (100 lbs/sq in). A jet pump-array for bypassing at a tidal inlet was installed at the Neerang River in Australia, in 1986 (ref. paper in print by the Florida Shore and Beach Preservation Association, 1988 conference in Gainesville, Florida). It has experienced debris problems.

The trap(s) shown in Figure 4 may be elliptical with the longest side parallel to the shoreline enabling the trap to catch more material from the wave-induced bottom creep (ÖZOY and YALCINER, 1983). If the longest side is perpendicular to shore it will catch more material from longshore drift, *e.g.* in migrating sand waves on the bottom (BRUUN, 1954). The trap may be located close to the limit of "active movement," that means somewhere between 1.5 and 1.8 H_b where H_b is the occurring maximum wave height at breaking during *e.g.* the "annual storm" (USACE, 1984 and later). That could be at 6 to 10 m depth, depending upon the exposure and profile movements. It will, therefore, increase the local bottom steepness and will consequently catch material moving mostly as bed load on the surrounding bottom depending on its efficiency (geometry), depth in the profile, depth of trap and wave action. Filling by material from the inside will mainly take place during storms and from the outside mainly during swell action following storms. The local bottom steepness and wave characteristics are the determining factors (SWART, 1974). In addition, the trap will collect material moving from the sides, *e.g.* in the form of the above mentioned migrating sand waves moving alongshore by combined current and wave action. The size of the material usually corresponds to the size normally found at that particular depth, *i.e.* a little finer than beach sand. But it could also be larger as found in sand waves (see BRUUN, 1954). If it is a little smaller than the beach material and is still used on the beach it may be less stable than the natural beach material resulting in a slightly gentler slope. At the trap itself the bottom will be (a little) steeper on the inside but (a little) flatter on the outside. Assuming a 3 m deep trap at 9 m depth (Danish North Sea and similar coasts), the increase in local profile steepness to 9 m depth theoretically is from 9/600 to 12/600 or from 1.5 to 2.0%. This would cause some local increased transversal transport away from the beach. But considering an area along the shore which could be about 25 times longer than the trap longshore dimension, the overall increase in steepness will only be from 1.5 to 1.52% which is so minimal that it is absorbed by variations in steepness that take place continually (BRUUN, 1954). Consequently, the increase of steepness will have no practical influence on the profile, including beach stability. Dredging of shoals or other deposits in the offshore zone might increase wave action slightly inside the dredged area but borrow areas are usually located so far out that the influence will be negligible. At tidal inlet shoals, dredging is beneficial to inlet hydraulics as well as to navigation. Anyhow, such problems can and should of course be looked into beforehand by proper wave analyses.

Backpassing of trap-material obviously does not generate new sand for the profile. If the profile as a whole is eroding, additional material *must be provided* to make up for the lost volume. This will be the normal case and will always be true for erosion associated with sea level rise (BRUUN, 1989, Vol. 2).

Trap design should be based on detailed knowledge of profile movements and sediment transport in the profile (SWART, 1974; LARSSON, 1988; KRAUS and LARSSON, 1988; BRUUN, 1989). It is stressed that its location must be far enough offshore so that it does not interfere with the nearshore (< 6 m) profile stability and, therefore, neither collides with profile nourishment which normally will not extend beyond 4–6 m depth. The remainder is left to nature's distribution.

ECONOMICS

The costs of sand pumping are dependent on a number of factors revolving around the fixed cost of the equipment, its degree of utilization, downtime due to mechanical or weather conditions, the efficiency of the pumping units and the heads (both static and dynamic) involved. The costs associated with mobilization and set up for a particular project may contribute significantly to the overall costs. It is necessary to maintain above critical velocities in pipelines, thus causing significant friction losses which mandate the use of high horsepower pumps. Implicit in the design of a sand pumping system is the need to avoid clogging or separation of pipelines which cannot be readily cleaned or repaired.

Economic aspects of sand bypassing (parallel to shore) differ from those involved in backpassing (perpendicular to shore). To achieve 100% bypassing, provision must be made to deal with both components of the gross littoral drift and the demands on the sand and pumping systems can vary considerably over the short term due to littoral drift inputs and variances in accumulations in a navigation channel.

The inclusion of a large (25,000 ± cubic yrd) fluidized sump in the sand handling bypassing system will smooth out the variable loads and permit relatively efficient and effective operation of the system.

The cost of a bypassing system is site specific and should not be judged on a cost per yard basis. On the other hand, backpassing by its nature suggests an intermittent but repetitive operation along a long stretch of beach which will allow the designers to maximize efficiency and utilization of the equipment while taking measures to minimize downtime. Again, large 20,000 ± cubic yard fluidized sumps spaced appropriately along a beach, *e.g.* for each 1.5–3–4.5 km, possibly located on an offshore shoal at a tidal inlet can provide replenishment of the sand in the sump within a reasonable time, and seems appropriate to the task. The accumulating load in selective sumps could be supplemented by split hull barge dumping. This could, of course, become the main supply, if trap-sand is less suitable for beach nourishment.

A number of pump and structural support options are available. They run from self-contained pumping systems on a jacked-up barge which is moved from sump to sump to fixed caissons capable of receiving a portable diesel power pumping station which could be moved from sump to sump. In all cases, a permanent fluidizing system could be installed at each sump and could be connected to a vertical standpipe permitting fixed hose and pipe connections not affected by moderate to severe weather conditions. A fixed submerged pipeline could run to the beach where a portable booster station and piping system would distribute the sand, as it now has been done in Denmark for five years (Figure 2) through a pipe installed in the bottom beyond the reach of seasonal fluctuations of the profile.

Cost studies suggest that sand could be moved from an offshore trap or intake (say 450 m or 1500 ft offshore) and distributed on the beach for about $4–5.00 per cubic meter ($3–3.50 per cubic yard), assuming favorable conditions regarding the scope and duration of the activity. This is a US-price indication. In Europe, the price would be somewhat lower due to better equipment, more experience and lower profits!

Example

Assume that we have rather strong erosion by which the shore loses 18,000 m^3 (24,000 yds^3) of material per 1,600 meters (1 mile) per year. This corresponds to about 11 m^3/m (15 $yd^3/yd \sim$ 5 yd^3/ft) or an annual shoreline (profile) recession of 1.2–1.5 m (4–5 ft). Furthermore, it is assumed that traps (sumps) connected to shore by a permanent or semi-permanent pipeline are established at 1,600 m (1 mile) intervals. General size depends upon the material needed. In this case trap size has to be 18,000 m^3 (24,000 yds^3) with an elliptical geometry as shown in Figure 4. Such configuration makes it easier to catch material from inshore, if washed out by storms, and from the offshore area by bottom creep occurring under modest wave action and swells (SWART, 1974; ÖZOY and YALCINER, 1983; BRUUN, 1989). It is furthermore assumed that dredging and dumping by split-hull barge costs about $2/$m^3$ (1.5/yd^3) provided modern and efficient equipment is used from a not too distant source. This is what the Danish Coastal Directorate pays, U.S. prices could be higher. Price, of course, is also quantity-dependent. A once per year maintenance schedule, as assumed, will allow the maintenance of a constant beach width. This is very desirable from a recreational as well as coastal engineering viewpoint offering better protection against storm tides and the accompanying dune erosion.

It is now estimated, *e.g.* based on dredged trap or tracer tests (*e.g.* BRUUN, 1967), that half of the trap is filled in by nature's action in one year while the remaining half may be delivered by a split hull dredge. Fill is pumped to shore by one pipe to shore per mile and distributed by 2 × 600 m (2 × 2,000 ft) shore pipes at either side (Figure 4). Based on economic evaluation, it is assumed that the unit price for such discharge from a "mammoth-trap" of 18,000 m^3 by fluidization method costs about $4.4/$m^3$ ($\sim$ $3.5/$yd^3$) all costs included for about 26,000 m (16 miles) of eroding shore. This is a practical figure for future large scale operations in Florida or elsewhere under similar conditions. The average price per unit volume based on 50% natural infilling then becomes $5.5/$m^3$ or $4.2/$yd^3$. This includes the cost of operation of all movable equipment, a fixed installation of bottom intake terminal and to-shore pipes. The pipeline on the beach for distribution of sand may be permanent or it may be placed at each single nourishment. Pipes in polypropylene may be of 20 to 24 inches (0.5–0.6 m) diameter.[1]

Considering relatively exposed shores, it is not likely that maintenance quantities of the order of 16 × 18,000 = almost 300,000 m^3/year (400,000 yd^3/year) can be delivered for a price like that. Prices could approach the double for

1. For further information on details of barge, pumps, and pipes the reader is referred to communication with the author. The Danish Coastal Directorate, Lemvig, will provide information on technical details of the permanent backpass installation.

such smaller quantities and would only come down to about \$5/m^3 (\$4/yd^3) with quantities 1.5 million m^3 (2 million yd^3) on a 5–10 year cycle of maintenance using conventional equipment. This schedule would leave the shoreline in constant recession leading to dune erosion during that period. This is indeed unfortunate. A competitive price could probably be achieved with a 5 or 10 year maintenance schedule of about 3 million m^3 (4 million yd^3) during which period the shoreline could recede about 30–50 m (100–150 ft). Such highly variable conditions, as mentioned above, are less desirable because they, at the end of the period, leave dunes and shore property vulnerable to erosion by storm tides. Too much fluctuation in beach width is not an attractive condition for a recreational beach. Administratively problems on the establishment of set-back lines are fouled up too! This has unfortunately been the normal practice for maintenance schedules of say 5–10 year cycles in the United States. Obviously the economy of such a system depends upon the efficiency of its operation. Mechanically the equipment should be kept reasonably busy on a year-round basis, just like normal dredging equipment. A moving spudded or jack-up dredge-barge or dredge seems preferable. It may be assigned to 1, 2, 5, 10 or more single offshore terminals at more than one location like the one established with great success in Denmark since 1984. A second plant is now planned which is a vote of confidence in the system. Suitable sand should, of course, be available and it usually is, but the search should be more intensified than the normal "scattered or hurried practice." Major sources of suitable sand are usually found on ocean shoals at tidal entrances where they are just a nuisance. The material may be transferred directly from the shoals to shore (BRUUN, 1989, Chapter 9) or it may be carried from the shoals to an offshore (permanently installed) terminal by a hopper dredge with either bottom doors, or split hull, or with pump-out capability using the permanent bottom terminal. Several Dutch and some U.S. dredgers "can do everything" (but preparing beds). The advantages in having a large offshore trap is obvious. One is that the trap may contain a large quantity of material available for transfer under most favorable conditions where all other equipment must close down. This increases costs. A fringe benefit, of course, is a certain amount of natural infilling of the trap. For pre-evaluation of infilling modes and rates tests on trap-dredging (*e.g.* BRUUN, 1967) at various depths is an obvious solution. Use of analytical models, as explained in the USACE/CERC report "Feasibility Study Dredging Nearshore Disposal Plan, Oregon Inlet, NC" (USACE, Wilmington District, 1983), is another solution. Theoretical aspects are dealt with by ÖZOY and YALCINER (1983) and BRUUN (1989, Vol. 2—Chapter 7). The natural infill sand may be a little finer than each sand and could be dumped first below the dredged sand just to "fill up."

CONCLUSION

In order to make nourishment of shores more effective and stable, *beach nourishment* should be replaced by some kind of *profile nourishment*. Table 1 gives examples as a function of grain sizes and equipment available.

In many instances, profile nourishment will be more economical than beach nourishment because cheaper material, if available, may be used in part of the offshore profile. Profile nourishment requires a higher degree of equipment-diversification, but it is available in Europe and is becoming available within the dredging industry within the U.S. Public agencies have been at the forefront of this important development (*e.g.* USACE by split hull dredge-barges, similar in the Netherlands and the Danish practice, Figure 2).

Backpassing from large offshore traps using a combination of conventional and non-conventional equipment to produce and maintain the trap and counting on a combination of filling by split hull or similar equipment and taking some advantages of natural back-filling seems to offer technical and economic benefits, particularly on maintenance schedules of one to three years which is preferable from a coastal protection and beach maintenance point of view with further influence on setback lines and other regulatory steps. Equipment needed includes split hull dredges or dredge-barges and (spudded or) jack-up dredge barges carrying equipment for transfer of material to shore. Such equipment is already available by the combined dredging and offshore dredging industry. It only needs to be "put together" and operated based on long range practical management principles.

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□ RESUMEN □

La literatura técnica publicada últimamente sobre el tema 'relleno artificial de playas' incluye un número de trabajos que califican el relleno como ineficiente y poco duradero. Parte de esta critica se fundamenta en experiencias prácticas.
Las pérdidas asociadas a los procedimientos normales de relleno de playa están causadas principalmente por la existencia de material excesivamente fino y por la ausencia de consideraciones adecuadas sobre el perfil.
Este articulo discute varias opciones para mejorar la estabilidad del relleno por medio de un "reperfilado" adecuado que significa un relleno en el perfil emergido (playa seca) y en el perfil sumergido, simultáneamente.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*

□ RÉSUMÉ □

Une bonne partie de la littérature sur les plages artificielles comprend des articles critiquant le remplissage de plage comme inefficace et peu durable. Une partie de la critique, reconnue comme objective et reposant sur l'expérience professionnelle est justifiée et raisonne sur l'expérience pratique. Les pertes qui sont associées aux techniques normales de remplissage de plage résultent surtout du matériel trop fin et de l'absence de prise en compte de la géométrie du profil. Dans cet article, plusieurs options sont discutées. Elles visent à améliorer la stabilité du remplissage par un profilage convenable, ce qui implique un remplissage simultané de la plage et du proche plateau continental associé, et l'extension des permis d'équipements disponibles. L'article considére aussi le retour de sédiment à la plage (introduction d'un équipement non conventionnel, ou dans la phase de développement).—*Catherine Bressolier (Géomorphologie E.P.H.E., Montrouge, France).*

□ ZUSAMMENFASSUNG □

Jüngere Fachveröffentlichungen über die künstliche Verbreiterung von Stränden bzw. den Sedimentauftrag auf Strände enthalten eine Vielzahl von Arbeiten, die diese Eingriffe in den Sedimenthaushalt als wenig effizient ansehen und nur eine kurze Wirkungsdauer der Maßnahmen prognostizieren. Diese ernstzunehmende Kritik wird durch zahlreiche theoretische Argumente wie auch praktische Erfahrungen erhärtet. Der Sedimentverlust bei normalen "Strandverbesserungen" wird i.w. durch eine zu kleine Korngröße des aufgetragenen Materials sowie unzureichende geodätische Aufnahmen der Strandgeometrie bzw. -morphologie verursacht. In diesem Aufsatz werden die verschiedenen Möglichkeiten diskutiert, wie die Stabilität der Stranderhöhung bzw. -verbreiterung durch ordnungsgemäße und angepaßte Strandprofilaufnahme verbessert werden kann. Eine positive Einflußnahme auf den Sedimenthaushalt des Strandes beeinhaltet auch gleichzeitig eine Miteinbeziehung des küstennahen Meeresbodens und eine Abwägung hinsichtlich des Einsatzes der zur Verfügung stehenden Ausrüstung. Die Betrachtung berücksichtigt auch das sog. "backpassing" an der Küste durch den Einsatz nichtkonventioneller, bzw. sich noch in der Entwicklungsphase befindender Ausrüstungsgegenstände.—*Ulrich Radtke, Geographisches Institute, Universität Düsseldorf, F.R.G.*