



## TECHNICAL COMMUNICATION

# Beach Nourishment as a Coastal Management Tool: *An Annotated Bibliography on Developments Associated with the Artificial Nourishment of Beaches*

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### INTRODUCTION

It is estimated that 70% of the world's sandy shorelines are eroding (BIRD, 1985). In the U.S. the percentage may approach 90% (LEATHERMAN, 1988). The worldwide extent of erosion suggests that eustatic sea-level rise is an underlying factor, although many other processes contribute to this problem (STIVE *et al.*, 1990). In many low-lying coastal areas, including the U.S., human impacts, such as the maintenance of tidal inlets and subsidence induced by groundwater and hydrocarbon withdrawals, have also made a substantial contribution to the erosion problem (NATIONAL RESEARCH COUNCIL, 1990). At the same time coastal populations are burgeoning worldwide (IPCC, 1990). The U.S. is no exception and this trend seems set to continue (CULLITON, 1990). This raises the fundamental question—what is the best response to the problem of shoreline recession?

Faced with progressive shoreline retreat and the inevitable loss of protective and recreational beaches, coastal communities have three basic alternatives, summarized by IPCC (1990) as: 1) retreat (relocate buildings and other infrastructure in a landward direction); 2) accommodate (*e.g.*, raise buildings to the projected higher flood levels); or 3) protect (build hard or soft structures). A fourth alternative is the unplanned response, 'no action'. In areas of dense population and highly developed infrastructure, protection is the preferred alternative (*e.g.*, FULFORD and GROSSKOPF, 1989). Hard structures are costly and

inflexible, and often have environmentally and aesthetically undesirable effects such as loss of the recreational beach. Thus, beach nourishment has become the coastal management "tool of choice" over the last several decades (NATIONAL RESEARCH COUNCIL, 1987; LEATHERMAN, 1991).

This bibliography reviews the evolution of beach nourishment as a coastal management tool from the earliest undesigned efforts in the 1920s to the much more sophisticated approaches utilized today. The major controversy concerning overall success of beach nourishment, the essence of which is exemplified in a series of papers by PILKEY and LEONARD (1990 and 1991) and rejoinders to them by HOUSTON (1990, 1991a), is also considered. This debate addresses one of the critical issues in this bibliography: does beach nourishment provide the benefits claimed by the coastal engineering community?

### Beach Nourishment Defined

*Beach nourishment or fill* can generally be defined as the artificial addition of suitable quality sediment to a beach area that has a sediment deficiency in order to rebuild and maintain that beach at a width that provides storm protection and a recreation area (CAMPBELL and SPADONI, 1982; STAUBLE and HOEL, 1986). This definition encompasses both *restoration*, a major sediment contribution to initially widen a declining beach, and *renourishment*, smaller periodic contributions for maintenance of the initial nourishment (FL DNR, 1986). Recently, the concept of *shore or profile nourishment* has gained pop-

ularity; this is the placement of fill across the active shore-normal profile landward of closure depth (*e.g.*, BRUUN, 1990; STIVE, 1991). Although other terms with slightly different connotations have been employed such as *recharge* (FOXLEY and SHAVE, 1983); *replenishment* (PILKEY and CLAYTON, 1987); and *reconstruction* (HEALY, 1990); the terms *nourishment* and *renourishment* are most widely recognized and therefore used in this bibliography.

#### An Overview of Beach Nourishment Projects

To date, over 640 km (400 miles) of U.S. coastline have been nourished, largely through public funding, at a total cost of about \$8 billion (DIXON and PILKEY, 1989). Overseas, beach nourishment has become very popular, particularly in developed countries such as Denmark, the Netherlands, Australia, and Great Britain (DELFT HYDRAULICS, 1987), but also in developing countries such as Brazil (VERA CRUZ, 1972) and Nigeria (IBE, 1991).

The first recorded beach nourishment project took place in 1922 at Coney Island, New York. From this time until 1950 some 72 nourishment projects or phases of projects were constructed in the U.S. (HALL, 1952). Over the last 20 years, application of beach nourishment has increased significantly. Project design has evolved from rudimentary dumping of sand on the beach to a quantitative exercise based on geomorphic principles and engineering theory (*e.g.*, DEAN, 1983; 1991). Since the 1970s, computer modeling of shoreline changes has developed and is now used routinely in beach nourishment design (*e.g.*, FULFORD and GROSSKOPF, 1989; HANSEN and BYRNES, 1991). Although significant advances in planning, monitoring, and maintenance of beach nourishment projects have been made, scientific theory for designing these projects remains relatively untested against field experience (*e.g.*, USACE, 1984).

The use of beach nourishment as a coastal management tool will probably continue its significant growth over the next few decades. However, the contemplated economic commitments to this management alternative by federal, state, and local governments is unprecedented. For instance, in northern New Jersey a Congressionally authorized nourishment project proposes to reinstate 19 km (12 miles) of beach at a cost of approximately \$200 million with projected maintenance costs over 50 years of about \$300

million (BOCAMAZO, 1991). Similarly, the total cost of the recently (1991) completed Ocean City, MD, nourishment project, including renourishment every four years for 50 years, was estimated to be \$342 million at the start of the project (KELLY, 1991).

#### The Preferred Alternative

Beach nourishment has become the preferred coastal protection alternative in recent years because it offers numerous benefits (DEAN, 1983; 1988; DELFT HYDRAULICS, 1987; LEATHERMAN, 1991):

- (1) the widened berm and advanced beach profile, in some cases combined with protective dunes, dissipate wave energy, which in turn acts to reduce damages from storms (DEAN, 1987).
- (2) the widened berm is esthetically pleasing, unlike hardened structures, and promotes tourism by easing congestion during peak vacation season;
- (3) the widened beach resets the long-term "erosion clock" and dispels the negative erosion-prone stigma of a coastal community;
- (4) it does not produce the negative downdrift effects commonly associated with rigid coastal engineering structures. In fact, the beach fill adds to the coastal sediment budget and benefits downdrift beaches and adjacent communities;
- (5) costs are generally lower and more evenly spread over time compared to hard structures;
- (6) projects are inherently flexible as the profile can adjust to incident hydrodynamic conditions; in addition, on closed basin systems such as the Great Lakes, beach fill can promptly adjust to rapid and significant oscillations of water levels (MADALON, 1991).

Beginning in the late 1800s, many communities began to utilize rigid coastal engineering structures to combat the problem of erosion. While certain hard stabilization projects have proven eminently effective in protection of upland areas (*e.g.*, WIEGEL, 1991), no additional sediment is provided to the beach system. Where a long-term erosion problem exists, and a shoreline is fixed in position by a seawall, erosion will continue unabated (DEAN, 1985) and the subaerial fronting beach will eventually disappear (KRAUS, 1987; 1988; TAIT and GRIGGS, 1990). This will often

necessitate modifications and strengthening of the structure, since it will be progressively undermined and experience a more severe wave climate (EVERTS, 1985). As the disadvantages of inflexible constructions emerged and the coastal recreation and tourism industry soared, communities have increasingly preferred nourishment over hard stabilization, particularly over the last 20 years (CAMPBELL, 1990). However, many densely developed coastal communities have yet to fully appreciate the inescapable long-term financial commitment to nourishment projects, including a number of renourishment cycles. Nonetheless, a further increase in use of beach nourishment is expected due to:

- (1) increasing coastal populations worldwide and pressure for beach-dependent recreational opportunities;
- (2) an increasing reluctance by governing political bodies to use hard structures on the coastline. Several coastal states have prohibited (e.g., Maine, North Carolina) or severely reduced (e.g., South Carolina) hard stabilization of their shorelines;
- (3) an increasing public awareness of coastal erosion problems on developed shorelines (LEMONICK, 1987);
- (4) recent interest in development of comprehensive coastal zone management programs (IPCC, 1990; DAVISON, 1992);
- (5) projections of rising sea level (NATIONAL RESEARCH COUNCIL, 1987).

Thus, the response to coastal erosion is being reduced to a straightforward choice between planned retreat and beach nourishment. Selection of the most feasible option will vary on a site-by-site basis due to a number of factors, particularly socioeconomic and environmental considerations (LEATHERMAN, 1988).

#### **The Polemic—Defining Success and Failure of Beach Nourishment Projects**

In spite of increasing use, our understanding of the performance of beach nourishment is still poor. This lack of understanding occurs because: 1) predictive models of beach behavior in response to varying hydrodynamic forces are still relatively crude tools for engineering purposes; and 2) most completed projects did not include adequate pre- and post-emplacement monitoring to allow for objective project assessment and necessary adjustment of designs. With our present under-

standing, each beach fill remains, in part, an educated experiment. Although many believe there is sufficient understanding and inherent flexibility within the procedure to produce practical and successful designs (DELFT HYDRAULICS, 1987), this confidence is not universally accepted.

During the 1980s, because of actual or perceived failure of numerous projects, beach nourishment began receiving heavy criticism as an ill-advised use of taxpayers' money (e.g., GILBERT, 1986). During this time, Pilkey and others (e.g., LEONARD, 1990b) began to contradict traditional coastal engineering methods used to design and evaluate such projects. Such criticisms are not isolated and coastal environmental groups advocate planned retreat as the only true solution to coastal erosion (DEAN, 1989).

The conclusions of PILKEY *et al.* have been challenged by many in the scientific and engineering communities (e.g., STRINE and DALRYMPLE, 1989; HOUSTON, 1991a). Nonetheless, contentions from the Pilkey camp have focused attention on the lack of high quality monitoring of U.S. beach nourishment projects and acted as a catalyst for renewed research efforts. This controversy underscores why beach nourishment is in the forefront of public policy decisions in the coastal zone.

#### **BIBLIOGRAPHY**

To allow for a better understanding of the relative merits of beach nourishment, this annotated bibliography reviews the evolution of beach nourishment projects, concepts, and designs throughout the world, but primarily in the U.S., over the last 40 years. This is the first comprehensive attempt to review the scientific, planning, and socioeconomic advances associated with beach nourishment projects. The annotated bibliography considers fundamental beach nourishment design parameters, including: borrow and native grain size, fill volume, fill density, pre- and post-project profiles, placement location along the profile, fill length, berm elevation and width, and transition at the ends of the fill.

Entries in the bibliography include benchmark or otherwise meaningful papers on design and/or performance of completed projects, results of laboratory experiments, or new concepts and techniques. Papers were selected on the basis of whether they made substantive advancements in the understanding of beach nourishment concepts. The rapid increase in application of beach

nourishment is reflected in publication chronology: approximately 70% of the entries are more recent than 1985 and over 30% were published in the 1990s.

Many of these papers and reports have been published in established scientific journals or proceedings of technical symposia. Other special papers have been issued as guidance or technical assistance documents by government agencies and universities. While journal publications and conference proceedings should be readily accessible to most readers through university and other libraries, the user may find it more difficult to obtain copies of special papers. Nonetheless, it was necessary to include these special publications because they represent significant progress in design, application, and understanding of beach nourishment.

### EVOLUTION OF BEACH NOURISHMENT PROJECTS

In the U.S., beach nourishment projects can be conveniently and logically divided into two eras. During the "early" period (1922–1952) projects were constructed without formal planning and design. During the "modern" period (1952 to present) beach nourishment in the U.S. has evolved into a highly technical, scientific and engineering endeavor. During this "modern" period, beach nourishment projects overseas, especially in European countries, have also increased in usage and advanced in design.

#### Early Nourishment Projects in the U.S.

The first possible case of beach nourishment occurred during the reign of Cleopatra (30–40 B.C.). She reportedly insisted that Egyptian sand be carried to the shore of Turkey so that she would not have to step on foreign soil (LEATHERMAN, 1991). More utilitarian demands for additional beach sand have surfaced along many of the world's shores during the twentieth century.

The U.S. has generally been the leader in the field of beach nourishment. The first recorded beach nourishment project took place in 1922 at Coney Island, New York, the site of the famous amusement park (HALL, 1952). Material for the project was dredged from New York Harbor and placed on a 1.0-km (0.7-mile) stretch of beach. In all, about 1.3 million m<sup>3</sup> of material were transferred to the island.

From this time until 1950, some 72 nourishment

projects or phases of projects were constructed in the U.S. (HALL, 1952). The vast majority of these were along the New York/New Jersey or southern California coastlines—the areas first subjected to intensive shoreline development in the U.S. Most early nourishment projects were, in essence, repositories for dredged material associated with construction or maintenance of harbors and navigation channels (HERRON, 1980; DOMURAT, 1987).

Construction of these early projects was based on general intuition and used little scientific or engineering knowledge and no quantitative data or design criteria. Little emphasis was placed on verification of predicted performance, and few if any post-project monitoring records were made. As such, it has been impossible to accurately gauge the geomorphic response or relative success of early projects (CAMPBELL, 1990).

#### Modern Nourishment Projects in the U.S.

Beach nourishment became an important coastal protection device by the middle of this century, with an almost exponential increase in its use over the last 40 years (SCHWARTZ and BIRD, 1990). The primary impetus for this turning point was the severe damage and erosion along the entire U.S. East Coast caused by several major hurricanes during the 1950s and the prodigious Atlantic Ash Wednesday nor'easter, March 5–8, 1962 (JARRETT, 1987). Since the early 1950s, the scientific basis for and application of beach nourishment projects have increased significantly. However, many projects during the 1950s through 1970s used borrow material from adjacent bays and lagoons which naturally contained high percentages of fine-grained material. Performance of these projects was poor (DEAN, 1983) and they were also highly impactive to benthic species (*e.g.*, REILLY and BELLIS, 1983). Since the late 1970s, reliance on offshore borrow sites which contain compatible grain sizes has generally produced more favorable results (ANDERS and HANSEN, 1990) and has been less impactive to estuarine and marine ecosystems (MARSH and TURBEVILLE, 1981; SALOMAN, 1982; LANKFORD and BACA, 1989).

As of the late 1980s, some 155 beaches have been nourished along the mainland U.S. at a cost of over \$8 billion (LEONARD, 1990a). This includes at least 380 separate fill emplacements on the Atlantic and Gulf Coasts (DIXON and PILKEY, 1989; LEONARD, 1990b) and 30 projects on

the Pacific Coast (CLAYTON, 1989). Since 1965, 31 projects covering 107 km (67 miles) have been completed in Florida (CAMPBELL, 1990), 17 projects in New Jersey, and 13 along the shores of North Carolina. In total, over 432 km (270 miles) of beach along the Atlantic seaboard have been nourished. Along the Gulf and Pacific Coasts over 160 and 48 km (100 and 30 miles), respectively, have been nourished (LEONARD, 1990a).

Several major beach nourishment projects in the U.S. are noteworthy and commonly considered successes. An early beach nourishment project was conducted in 1951–52 at Harrison County, MS (USACE, 1984). This 42 km (26 mile) project has withstood several major storms along this generally low-energy coastline of the Mississippi Sound (USACE, 1987). This is an early example of a successful nourishment project that has provided both storm protection and important recreational amenities (WALTON and PURPURA, 1977). Although it is worth noting that the project is located along a relatively sheltered mainland shore of a barrier lagoon and the beach fill fronts and helps protect an existing large seawall.

At Rockaway Beach, NY, 10 km (6.2 miles) of beach was nourished in three phases totalling 4.7 million m<sup>3</sup> (6.2 million yd<sup>3</sup>) from 1975–1977 for \$14.3 million (NERSESIAN, 1977; HOBSON, 1977). Although Rockaway Beach has undergone multiple and massive episodes of beach renourishment since the 1920s (NERSESIAN, 1977), the 1975–1977 project was notable for both its size and resourceful nourishment design. The project employed extensive pre-project planning and field surveys, contemporary and innovative dredging, state-of-the-art modeling, and construction and post-project monitoring (NERSESIAN, 1977).

By far, the largest, most successful, and most publicized beach nourishment undertaking was the Miami Beach, FL, project, fully completed in 1980. Over 10 million m<sup>3</sup> (13 million yd<sup>3</sup>) of sand was placed along 17 km (11 miles) of coast at a cost of approximately \$64 million (1980 dollars) (USACE, 1975). The Miami project has shown remarkable resiliency, even under moderate hurricane activity (*i.e.*, Hurricane David in 1979). In addition to providing storm protection, the project's recreational amenities have helped revitalize Miami's international tourist industry.

Most recently, a nourishment/protective dune project at Ocean City, MD, employed the integration of numerous state-of-the-art numerical

models to provide 100-year storm protection to 12.3 km (8 miles) of shoreline using 4.6 million m<sup>3</sup> (6.0 million yd<sup>3</sup>) of beach fill in two phases (USACE, 1989). The Ocean City project is noteworthy because calculation of fill volume included the entire active profile out to closure depth; *i.e.*, enough sediment was placed initially so that once the beach adjusted to the equilibrium condition, the design subaerial width (30-m or 100-ft berm) was achieved (FULFORD and GROSSKOPF, 1989; HOUSTON, 1991b). Although this significantly increased initial cost, long-term savings from reduced maintenance was expected to more than offset the original outlay (ANDERS and HANSEN, 1990). At the time of this writing, the project had just experienced a significant northeaster (January 4, 1992). While the storm removed most of the protective dune, the project significantly reduced damages that would have otherwise occurred. Estimated cost to refurbish the project was \$9.5 million (HOUSLEY, 1992). The widespread interest in design performance compared to the frequency of the January 4th storm and funding commitments for reconstruction and maintenance over the 50-year life of the Ocean City project reemphasize the prominent attention that beach nourishment will receive in future coastal management strategies.

Other renowned projects at Atlantic City, NJ, (1963 and 1970) (EVERTS, 1974; SORENSEN, 1988) and Carolina (1965) and Wrightsville (1966) Beaches, NC, (PEARSON and RIGGS, 1981; JARRETT, 1987) performed below expectations and have been labelled by some (*e.g.*, PILKEY, 1989) as total failures. Major design flaws, such as incompatible grain size (WALTON and PURPURA, 1977), and failure to understand or properly consider inlet dynamics (WALTON and DEAN, 1976; ASHLEY, 1987), initial profile re-equilibration, depth of closure, and long-term erosion rates, severely handicapped these and other earlier projects (*e.g.*, CHOU, 1983).

Densely developed areas such as Atlantic City, NJ, Ocean City, MD, Rockaway Beach, NY, and Miami Beach, FL, have received major nourishment projects to protect extensive infrastructure. In turn, nourishment can increase real estate values (BLACK, 1988) and induce (whether purposefully or not) new development or rehabilitation of existing development (STRONGE, 1990; BODGE, 1991). As such, governments regulating these densely populated areas have made a financial commitment to fix the position of the shore-

line and thus maintain, through renourishment, a stable and protective beach. Consequently, it is appropriate to ask what role the federal and/or state taxpayers should bear in financing expensive, site-specific coastal restoration projects (LEATHERMAN, 1991). Should such projects be primarily or entirely funded locally or privately by the direct beneficiaries (*e.g.*, OLSEN, 1982)?

### Beach Nourishment Projects Overseas

In the U.S., especially along East and Gulf barrier coasts, hydrodynamic conditions (microtidal) and sediment characteristics (fine sandy beaches) are relatively uniform. This has tended to produce somewhat homogenous beach nourishment designs and execution techniques. Overseas, a wider range of sediment size, wave energy and tidal range has led to a more varied evolution of design approaches, placement locations, and execution. The most active nations have been the Netherlands, Germany, Great Britain, Denmark and Australia.

Internationally, the Dutch have been leaders in the use of beach nourishment and in scientific advances that have reduced cost of this procedure. In combination with nourishment of the berm, the Dutch rely on natural and artificially reinforced sand dunes to provide a major element in coastal defenses against storms. Using this strategy, 50 projects, totalling 60 million m<sup>3</sup> (78.5 million yd<sup>3</sup>) of fill, were completed in the Netherlands between 1952–1989, most being since 1970 (ROELSE, 1990). In addition, the Dutch are actively investigating direct placement on the subaqueous profile and attempting to change national policy to allow this (ROELVINK, 1989). The Dutch are clearly striving toward a fully integrated approach which addresses the dune, the berm, and the subaqueous profile.

Another noteworthy overseas effort is that on the island of Sylt, Germany. Numerous projects with unique designs have been constructed here during the 1970s and 1980s (DETTE, 1990). Also, an orderly post-project monitoring system has been conducted since the first project was constructed in 1972. At Norderney, one of the East Friesian Barrier Islands, beach nourishment started in 1951, with five subsequent renourishments (KUNZ, 1990). The procedure for renourishment continues to be refined based upon experience.

In Great Britain, the widespread natural occurrence of shingle (or gravel) beaches has led

to increasing and successful use of shingle nourishment and recharge (THORN, 1960; EDDISON, 1983; FOXLEY and SHAVE, 1983; BEVEN, 1985; NICHOLLS and WEBBER, 1987; NICHOLLS, 1990), especially the southeastern coastline at locations such as Hayling Island, Hampshire (HARLOW, 1985) and Seaford, Sussex. The scale of projects is increasing: at Seaford 1.5 million m<sup>3</sup> (2.0 million yd<sup>3</sup>) of sea-dredged gravel was placed at a cost of 12 million sterling (about \$24 million) (NICHOLLS, 1990). Back-passing or recharging (hauling material from the terminus of the littoral cell to its origin) is a fundamental design element. Sand nourishment has also been practiced successfully in England (CRAIG-SMITH, 1973; WILLIS and PRICE, 1975), most notably at Bournemouth (WILLMINGTON, 1983; LELLIOTT, 1989).

To abate erosion of unconsolidated cliffs on the Gulf of Georgia, Vancouver, Canada, Downie and Saaltink (1983) report a case where sand nourishment proved unsuccessful but cobble nourishment worked. At Moulin Blanc, Brest, France, nourishment was completed in 1978 by pumping 67,000 m<sup>3</sup> (87,600 million yd<sup>3</sup>) of sand to create a beach 1000 m (3,300 ft) long and 100–120 m (330–393 ft) wide (HALLEGOUET and GUILCHER, 1990). Three small-scale nourishment projects on the French Mediterranean coast, at Cannes, Monaco, and Marseille, have performed satisfactorily and been well-received by the public (ROUCH and BELLESSERT, 1990). In Praia da Rocha, Portugal, major nourishment projects were undertaken in 1970 and 1983 along the Mediterranean Coast (PSUTY and MOREIRA, 1990). Near Zeebrugge, Belgium, 8.5 million m<sup>3</sup> (11.1 million yd<sup>3</sup>) was dredged offshore and placed along 8 km of beach (KERCJAERT, 1986).

At the demand of Tokyo citizens for increased recreational amenities and waterfront access, nine beach nourishment projects supporting seaside parks have been constructed in Tokyo Bay since the early 1970s (KOIKE, 1990). Overall, 21 beaches have been nourished in Japan, with plans for 66 more projects (NAKAYAMA, 1982). However, most of the Japanese coast is being stabilized by hard structures, as government officials desire a so-called “permanent” solution to the erosion problem. It will be interesting to contrast the relative success of this policy to the Dutch approach over the long-term.

Between 1975 and 1987, 18 separate beaches (19.3 km) along the shore of Port Phillip Bay,

Australia, were successfully nourished (BIRD, 1990). To date 4.7 million m<sup>3</sup> (6.1 million yd<sup>3</sup>) of fill has been applied to the beach system of the Gold Coast, Queensland, Australia (SMITH and JACKSON, 1990b). Based on several years of monitoring, the Gold Coast projects have generally been described as successful. In New Zealand, the concept of beach nourishment gained increasing acceptance as an alternative to beach erosion problems during the 1980s and a wide variety of projects were constructed (CARTER and MITCHELL, 1985; DE LANGE and HEALY, 1990; HEALY, 1990; KIRK, 1978; KIRK and WEAVER, 1982 and 1985).

Many other nations began to endorse the use of beach nourishment in the 1980s. Most notably, the Soviet Union, with establishment of the Scientific-Industrial Association (S.I.A.) Gruzmorberegoshahita in Soviet-Georgia in 1981, took a significant philosophical shift away from hard structures. Six nourishment projects were constructed along the Black Sea Coast in the 1980s, accounting for 70 ha. of additional beach along 47.5 km (29.5 mi) of coast (ZENKOVICH and SCHWARTZ, 1988; KIKNADZE, 1990).

In Namibia, southern Africa, in an unusual application of beach nourishment, a large dike composed of beach sand and a dewatering system were constructed about 300 meters seaward of the original beach to protect a diamond mine (MOLLER, 1986; MOLLER and SWART, 1987). A 1.7 km (1.1 mi) sand breakwater was constructed at Saldanha Bay, South Africa connecting two fastlands (ROUSSEAU, 1976; ZWEMMER and VANT HOFF, 1979). To do this, a base 6.5 m (21 ft) below MLW was formed with 15 million m<sup>3</sup> (19.6 million yd<sup>3</sup>) of sand dumped from hopper dredges, and atop this, a further 5 million m<sup>3</sup> (6.5 million yd<sup>3</sup>) of sand was placed. In Durban, South Africa, beach nourishment was found to be by far the most effective solution to a long-term erosion problem (LAUBSCHER, 1990). More widespread application of beach nourishment in South Africa is being advocated.

To protect prime tourist infrastructure at Varadero Beach, Cuba, several fill placements have been conducted over the last two decades with increasing land use planning (*i.e.*, construction setbacks) and success (SCHWARTZ, 1991). Projects have also been constructed in Brazil (VERACRUZ, 1972; LEATHERMAN, 1986), Singapore, and Bora Bora (WIEGEL, 1987) and Nigeria (IBE, 1991).

## EVOLUTION OF DESIGN CONCEPTS

For governments attempting to promote taxes, bond referendums, or otherwise raise money for beach nourishment, or for those jurisdictions that have already funded projects, accurate designs are essential for predicting beach fill longevity and maintenance requirements. The basic aim of beach nourishment is to elevate the beach and advance the shoreline a given distance and hence realize all the consequent benefits such as increased storm protection (DEAN, 1987). Impressive coastal accretion at sites where mining waste is dumped directly into the sea clearly demonstrates that if enough sand/gravel is placed on a shoreline, a substantially wider subaerial beach can be created (*e.g.*, BIRD and CHRISTIANSEN, 1982; PASKOFF and PETIOT, 1990). However, beach nourishment demands quantitative understanding of this process, particularly what volume and grain size of sand is required to attain a specific increase in subaerial beach width and what is the lifetime, and hence the renourishment frequency, of that beach (*e.g.*, DEAN and GRANT, 1989).

As characterized by numerous workers and summarized by DELFT HYDRAULICS (1987), many present design concepts remain relatively untested against actual field performance: "an exact forecast of the behavior of the beach fill is not possible, not even in the case where a large number of data of the relevant area is available." EGENSE and SONU (1987) reiterate as follows: "At the present stage of technology, beach nourishment is more art than science." The behavior of nourished and natural beaches is subject to the same uncertainties, and WIEGEL (1987) argues that our present inadequate quantitative knowledge of natural beach processes handicaps dependable estimates on how well nourished beaches will perform. From a fundamental perspective, future shoreline evolution will always be stochastic, even with complete understanding of all processes, as the underlying driving forces (waves, storms, etc.) are themselves stochastic (NATIONAL RESEARCH COUNCIL, 1990). Thus, probabilistic predictions of nourishment performance must be the goal. When combined with high precision monitoring (*e.g.*, DAVIS, 1991), this will provide all the information required to successfully and optimally plan and implement beach nourishment.

As previously discussed, between the 1920s and 1950s, beach nourishment schemes in the U.S. were essentially undesignated and completely em-

pirical. Subsequently, engineers and coastal scientists have been progressively developing more sophisticated predictive nourishment designs and adjusting design parameters in attempts to improve project performance (*e.g.*, VALLIANOS, 1974; LEADON, 1991). The 1970s marked the advent of computer-aided beach nourishment design. Computer designs now include one-line, two-line, and N-Line planform models (PERLIN and DEAN, 1985; BRAMPTON and MOTYKA, 1987; HANSON, 1987), and cross-shore dune erosion models and profile models (KRIEBEL and DEAN, 1985; LARSON, 1990). Computer-based models also ease integration of the many different parameters which must be considered in overall design (FULFORD and GROSSKOPF, 1989; HALES, 1991).

It is difficult to summarize the many different design methods for beach nourishment. The most notable contrast is between the more empirical design approach based on practical experience often used in Europe (*e.g.*, DELFT HYDRAULICS, 1987) and the more theoretical design approach recently developed in the U.S. (*e.g.*; CAMPBELL, 1990). In the Netherlands, trend extrapolation of historical shoreline positions, based on beach profiles and measured since the middle of the last century is the basis of design (ROELSE, 1990). Few, if any other countries have historical data of this quality. Also, significant grain size differences between the fill and native sand in the Netherlands are rare and need not be considered (ROOLSE, 1990).

A brief review of U.S. design concepts and experience follows.

#### Grain Size

Compatibility of the fill material is a major consideration, particularly as such fill is rarely if ever identical with the native beach sand (USACE, 1984). It is not uncommon for fill to contain silts and clays which will be winnowed and carried away from the beach in suspension. Early projects did not consider this factor, which contributed to poor performance. Native sand can be used as a reference hydrodynamically-stable population to which any potential beach fill can be compared. Starting with KRUMBEIN (1957), a number of workers (KRUMBEIN and JAMES, 1965; DEAN, 1974) have examined these relationships, culminating in the work of JAMES (1975) which is still the standard USACE (1984) method. The method is based upon two factors: 1) the overfill factor;

which predicts how much fill will remain after sorting by hydrodynamic processes; and 2) the renourishment factor, which predicts how often renourishment will be necessary when compared to performance of the native sand.

These concepts undoubtedly placed the design of beach nourishment on a more quantitative basis. However, this approach assumes that native and borrow distributions are nearly lognormal and has not been fully tested in the field (USACE, 1984; STAUBLE and HOLEM, 1991). It is generally agreed that coarser grain sizes are more stable (DEAN, 1983; ROELLIG, 1989), although these benefits have limits (LARSON and KRAUS, 1989; DEAN, 1991). Although BRUUN (1990) among others has argued that basing nourishment design purely on grain distribution comparisons is an obsolete principle, it is still a fundamental parameter for the design of beach nourishment projects in the U.S. (ANDERS and HANSEN, 1990).

#### Cross-Shore Design

It is not often appreciated that most of the active beach profile is submerged (LEATHERMAN, 1991). The entire active profile must be moved seaward for nourishment to be successful. Thus, the seaward limit of the active beach profile for purposes of beach nourishment is a problematic but very important determination (BRUUN, 1986; HANSEN and LILLYCROP, 1988). Early nourishment projects did not consider the offshore profile (VALLIANOS, 1974; JARRETT, 1987), or if they did, utilized unrealistic slopes which caused excessive losses of the subaerial beach (HANSEN and LILLYCROP, 1988). HAL-LERMEIER (1981) developed a wave-based profile zonation, including the depth definitions:  $d_1$ —the annual seaward limit of significant longshore transport; and  $d_2$ —the annual seaward limit of significant on/offshore transport.  $d_1$  was suggested as the seaward limit for beach nourishment design. Field observations support this recommendation (HOUSTON 1991b; HANDS, 1991).

The equilibrium profile concept can be applied to beach nourishment design (DEAN, 1983; 1991):

$$h(y) = Ax^{0.67} \quad \text{Eq. 1.}$$

where  $h(y)$  is the depth at horizontal distance  $x$  and  $A$  is a scale factor which can be related to grain size. This is a more dynamically-based model than used by the USACE (1984). Grain size is parameterized via the  $A$  parameter. Nourished



beach profiles can be classified into three types: 1) intersecting; 2) non-intersecting; and 3) submerged profiles depending on the relative grain size of the fill and native materials (DEAN, 1991). The coarser the fill, the smaller the required fill volume, and the steeper and more stable the resulting beach. While benefits of using coarser-than-native beach fill (*e.g.*, CHRISTIANSEN, 1977) are readily apparent from this method, the original beach characteristics can be adversely altered in this case.

The work of HALLERMEIER (1981) and DEAN (1983; 1991) are fundamental papers in the design of beach nourishment. Although these works still remain relatively untested in the field, the importance of the depth of closure concept as it effects the location of borrow sites and wave refraction has been reinforced during actual storm conditions (COMBE and SOILEAU, 1987). Further developments in cross-shore modeling (*e.g.*, FEMA, 1986; HALLERMEIER and RHODES, 1988; HANSEN and BYRNES, 1991) have demonstrated the importance of artificial dunes as a reservoir of sand and barrier to waves and flooding. U.S. Federal agencies have adopted regulations in recognition of this function (FEMA, 1988). As such, U.S. nourishment designs are beginning to more closely emulate the primary approach to coastal defense utilized by the Dutch (ANONYMOUS(2), 1990).

### Longshore Design

Nourishing a length of shoreline causes it to move seaward, which changes the littoral drift rates near the project ends (*e.g.*, CHOU, 1983). DEAN (1983) developed a predictive model or "half-life" equation for fill longevity of a rectangular beach nourishment. This model assumes that all losses are caused by longshore transport and predicts:

$$t_{50} = 0.172(l^2/h_w^{2.5}) \quad \text{Eq. 2.}$$

where  $t_{50}$  is retention time of half the fill within the project area in years;  $l$  is longshore project length in kilometers; and  $h_w$  is the wave height in meters. This model predicts that beach fill is most effective under low energy wave climates, or when the project length is long. It is worth restating that any sand moved alongshore is not 'lost'; rather it generally benefits adjacent beaches (DEAN, 1987; DEAN and GRANT, 1989). However, nourishment placed as a sand "groin" or instantaneously released in mass has been shown to induce

lee-side erosion in downdrift areas (DETTE, 1977; GROVE, 1987). Other longshore configurations (*e.g.*, adjacent to a terminal groin) are considered by CAMPBELL (1990).

### Placement

Clearly the location, delivery method, and timing (seasonality) of beach fill placement are important design considerations. Placement location, be it anywhere between the dune and the storm bar (SMITH and JACKSON, 1990a); or even across the entire profile (BRUUN, 1990) is considered by some to be one of the most important design parameters in the performance of beach nourishment projects. Placement timing, to take advantage of seasonal reversals in longshore transport direction and shore-normal profile changes (*e.g.*, EVERTS, 1974; SORENSEN, 1988; STAUBLE and HOLEM, 1991), in addition to environmentally benign "windows" (*e.g.*, BACA and LANKFORD, 1988; WOODSELL, 1989), can also be a significant design consideration for optimizing fill residence time.

In the U.S., fill is generally placed on the sub-aerial beach by dredge and pump, and hydrodynamic processes are left to redistribute material across the profile (USACE, 1984). This approach simplifies contractor payment per volumetric unit of material delivered, but raises delivery costs. Pumping to the subaerial beach is, at least in part, the result of deeper drafts of U.S. type hopper dredges compared to European dredges and the shallow and gently sloping profile along the East and Gulf Coast of the U.S. This limits direct dumping across the profile by split-hull dredges (WALTON and PURPURA, 1977; BRUUN, 1990). However, the technical feasibility of disposal of beach quality dredge material in shallow depths where it will become incorporated within the beach system and nourish it, is being investigated (HANDS, 1991; HANDS and ALLISON, 1991). Similarly, in Europe serious thought is being given to the benefits of profile nourishment in which sand is placed on the subaqueous part of the profile at a substantial reduction in delivery cost (ROELVINK, 1989; BRUUN, 1990 and 1991; STIVE, 1991). If the difficulties in controlling and identifying the quantity of fill placed can be solved, placement across the profile may offer significant cost savings for beach nourishment projects.

Placement on the offshore storm bar has been attempted in wave tank experiments (KAMPHUIS and MOIR, 1977), in a few limited cases

on the Gold Coast, Australia (JACKSON, 1985), and along the U.S. Pacific Coast (CLAYTON, 1989). JACKSON and TOMLINSON (1990) and BOCZAR-KARAKIEWICZ and JACKSON (1990) strongly advocate the benefits of this procedure. The ongoing monitoring of the Gold Coast beaches should provide much useful data on the utility of this procedure (SMITH and JACKSON, 1990a). Alternatively, at Sylt, Germany, a large sand groin was placed, which acted as a feeder beach so that material was gradually redistributed downdrift. Although project performance was considered successful, problems include lee side erosion and predictions of longshore transport rates and direction (DETTE, 1977). Other unique placement techniques with limited application and uncertain performance to date include subaqueous and subaerial shore-parallel retention dikes or breakwaters to forestall fill losses (*e.g.*, DEAN, 1983; CHILL, 1989); sublayering of coarser over finer material (*e.g.*, MACINTOSH and ANGLIN, 1988); regularly spaced berm stockpiles (GLASTER and SWARTZ, 1990); and fill stabilization through beach face dewatering (PARKS, 1990).

#### Project Evaluation

Concern about the effectiveness of beach nourishment projects, particularly actual versus predicted performance has been mounting (MORRIS, 1991). Many coastal environmental groups liken beach nourishment to "throwing dollar bills in the ocean" (DEAN, 1989). The controversial conclusions of an assessment of 155 nourished beaches in the U.S. (*e.g.*, PILKEY and CLAYTON, 1987; 1988; DIXON and PILKEY, 1989 and 1991; LEONARD, 1988; 1989; 1990a; 1990b), support such a view, including:

- (1) With a few exceptions, beach nourishment projects have short lifetimes—less than 5 years;
- (2) The density and grain size of the beach fill makes no difference to overall stability or lifetime;
- (3) Nourished beaches typically erode much faster (1.5 to 12 times) than their natural counterparts;
- (4) Nourished beaches do not recover from storms like natural beaches;
- (5) The main factor in project failure is storms.

These conclusions are in conflict with the design principles previously outlined and have been rebutted in the scientific and engineering com-

munity (*e.g.*; ANONYMOUS(1), 1985; STRINE and DALRYMPLE, 1989). In particular, HOUSTON (1990; 1991a; 1991b) questioned the methodology of LEONARD (1990a) which equated re-equilibrium with massive beach erosion and project failure, and which used of a half-life criteria instead of total life to classify project performance. Erosion rate data used by Pilkey to assess beach nourishment performance has also been considered suspect as it included a range of qualitative or semi-quantitative sources, including local media (HOUSTON, 1991a). However, basic reputable data, such as time-series surveys of beach profiles (*e.g.*; EVERTS, 1974) are difficult or impossible to obtain for most of the 155 nourished beaches considered by Pilkey and often necessitates the use of less reliable sources. To quote DIXON and PILKEY (1989), "fragmentary information about a project is the unfortunate rule rather than the exception."

Conflicting statements about project performance are apparent elsewhere. The NATIONAL RESEARCH COUNCIL (1990) describes the late-1980 Indialantic beach nourishment in Florida as unsuccessful, because over half the fill was lost alongshore in the first three months of the project. However, STAUBLE and HOLEM (1991) describe detailed time series of the performance of the remaining beach fill over seven years as a success. In particular, a 20 to 25 year return period storm in late 1984 caused no dune scarping. It is clear that project performance can only be objectively assessed if high quality monitoring data is available and considered using commonly agreed upon criteria of success and failure (STAUBLE and HOEL, 1986).

PILKEY and CLAYTON (1987) and PILKEY (1988b) argue that present approaches used to predict lifespans of U.S. nourishment projects are inadequate and that "predictions of beach durability are always wrong" (PILKEY, 1989). In contrast, the State of Florida reports that "the vast majority of restoration projects implemented in Florida are performing as designed or in some cases are exceeding design standards in terms of performance" (FL DNR, 1986). In the Netherlands, where conclusions of Pilkey *et al.* have been seriously questioned (STIVE, 1991), evaluation of selected projects showed that seven out of nine performed as well as expected or exceeded their design life (ROELSE, 1990).

In conclusion, project evaluation of beach nourishment has generally been poor and qualitative

in nature, particularly in the U.S. (STAUBLE and HOEL, 1986). Concerns such as widespread lack of post-project monitoring by objective parties and frequent lack of commitment or inability of project sponsors to properly maintain nourished beaches are undeniably important issues and justifiably brought to the fore by PILKEY. Project evaluation should be based upon objective criteria of success and failure and detailed scientifically-based analyses (*e.g.*, ASHLEY, 1987; THOMPSON, 1987). In contrast, in Europe and Australia, post-nourishment monitoring is much more the norm and accepted as a part of the overall project (*e.g.*, the Danish North Sea coast; MOLLER, 1990). Lessons learned from such detailed monitoring are used interactively to improve later phases of the project as well as improvements in the overall science (*e.g.*, CHAPMAN, 1980; LELLIOTT, 1989).

#### STATE-OF-THE-ART: FUTURE STUDIES

Beach nourishment has been shown in many ways to be in its infancy as a tool in coastal management. As exemplified by the creation (LARSON, 1990) and recent testing (*e.g.*, HANSEN and BYRNES, 1991; HALES, 1991) of shoreline change and storm-induced beach erosion modeling such as SBEACH, considerable developments are to be expected in coming years. These will refine our approach to existing problems and help develop solutions to new problems as they emerge.

Routine post-project monitoring (*e.g.*, ROELIG, 1989) is likely to become the norm after the debate between PILKEY and LEONARD (1990; 1991) and HOUSTON (1990; 1991a; 1991b). Detailed procedures for standardization of both short- and long-term monitoring have been advanced (*e.g.*, STAUBLE and HOEL, 1986; STAUBLE and HOLEM, 1991) and is recommended in USACE (1984). Clearly, omitting this stage of the project is a false economy (VALLIANOS, 1974). The importance of measuring the entire active profile to depth of closure should be stressed: for instance, compare results for Atlantic City, NJ, (only surveyed to wading depth) (SORENSEN, 1988; WEGGEL and SORENSEN, 1991), with those from Ocean City, MD (surveyed beyond depth of closure) (HOUSTON, 1991b). The design procedures outlined in the annotated bibliography (*e.g.*, JAMES, 1975; HALLERMEIER, 1981; DEAN, 1983 and 1991) are largely untested and would benefit greatly from good quality da-

taset for validation. Such data also maximizes the effectiveness of 'sediment management' for individual projects and should be used interactively to predict when renourishment is necessary.

As part of this monitoring, particular attention should be paid to grain size and fill/native sand compatibility. This is more expensive to monitor but the value of such data should be stressed (DAVIS, 1991). For instance, how does material arriving at the beach compare with the grain size composite predicted from sampling at the borrow site (*e.g.*, LEONARD, 1990b)? Another important question is, when does the fill material come to so dominate beach characteristics that native sand characteristics become irrelevant (STAUBLE and HOEL, 1986)?

Long-term economics of sand delivery to the beach, including advances in dredging technology (*e.g.*, CHISHOLM, 1990); establishment of offshore transport chains, backpassing, and permanent offshore pumping plants (BRUUN, 1990 and 1991); artificially induced inlet shoal bypassing (KANA, 1989); and innovative utilization of potentially abundant, unusual borrow materials (*e.g.*, oolitic aragonite, CUNNINGHAM, 1966; OLSEN and BODGE, 1991) should be carefully examined, as this could greatly increase viability of beach nourishment. In the State of New Jersey, linking of inlet maintenance to nourishment of the adjacent beaches, rather than deep water disposal, has become part of the State Coastal Zone Management Plan (MAURIELLO, 1991). DEAN (1988) has noted large losses of sand to Florida's coastline due to poor management of inlet maintenance. As a result, the States of Florida and South Carolina have recently mandated that beach-quality sand dredged from inlet navigation channels be placed on a nearby eroding beach (FL DNR, 1989; SOUTH CAROLINA COASTAL COUNCIL, 1991). The New Jersey, Florida, and South Carolina models are expected to be applied more widely in the future.

Conceptually, profile nourishment is an attractive method for reducing delivery cost (BRUUN, 1990) and quantitative experiments in the U.S. (SCHWARTZ and MUSIALAWSKI, 1977) and the Netherlands (STIVE, 1991; VAN ALPHEN, 1990) suggest its feasibility. The technical feasibility of such procedures, as part of a wider program on dredged material disposal, is being examined in the U.S. and is expected to produce important methodologies (HANDS, 1991).

The State of South Carolina recently passed

laws and promulgated regulations that institute criteria for design, maintenance and financing for accreditation of beach nourishment projects (SOUTH CAROLINA COASTAL COUNCIL, 1991). These and other accreditation criteria (*e.g.*, DEAN and GRANT, 1989) are probably a progenitor for the treatment of beach nourishment by existing state programs and by a pending federal erosion management program that encourages building setbacks with the incentives of Federal flood insurance (NATIONAL RESEARCH COUNCIL, 1990; WOOD, 1990; DAVISON, 1992). However, long-term financial commitments by project sponsors; limited offshore sources of economical beach quality sediment; ever changing environmental regulations; project performance guarantees; and assurances for immediate post-storm reconstruction (KANA and STEVENS, 1990) are problematic issues regarding accreditation of beach nourishment projects by governmental agencies regulating coastal land use and development. Given future economic and political uncertainties, it may be impossible to assure long-term (*i.e.*, 50 to 100 years) commitments to project maintenance (DAVISON, 1990). Again, this reiterates the need for standardized post-placement monitoring.

The increasingly developed character of the world's coastline will undoubtedly lead to increasing demand for beach nourishment. Hopefully, this will be undertaken within the context of sensible management plans that plan for sustainable use of the coastal zone (IPCC, 1990). In addition, to population and development pressure, accelerated sea-level rise will also increase demand for beach nourishment (WEGGEL, 1986; DEAN, 1987; LEATHERMAN and GAUNT, 1989; STIVE, 1991). This raises a number of new questions, particularly the seaward limit of the beach profile over long timescales and the long-term availability of sufficient sand. Innovative design methods utilizing structures to forestall fill losses (*e.g.*, LUDWICK *et al.*, 1987) may become necessary (WEGGEL, 1986). Undoubtedly, these issues will receive considerable attention in coming decades.

The Dutch government has recently decided to maintain the position of its existing coastline, with beach nourishment having the dominant role (ANONYMOUS(2), 1990). Annual volumetric requirements of 6–10 million m<sup>3</sup> are expected (LOUISSE and KUIK, 1990). Taking this policy a stage further, the possibility of seaward coastal defense is being considered: that is, reduce the

impacts of future erosion by building the coast seaward at selected locations (PLUIJM, 1990). If this policy is adopted, volumetric requirements for nourishment will be even greater, at least in the short-term. Similarly in Britain, beach nourishment is expected to form a major element of coastal management in the future (LACEY, 1991). In the U.S., a comprehensive 'Save Florida's Beaches: A Resource Protection Management Initiative' has been proposed to preserve and effectively manage the State's predominant resource of the future (FLORIDA, TASK FORCE FOR BEACH MANAGEMENT FUNDING, 1991). It is apparent that recreational demands and their economic power are the primary driving force for Florida's policy.

While European countries such as the Netherlands (ANONYMOUS(2), 1990) and Denmark (MOLLER and SWART, 1987) presently lead the world in integration of beach nourishment with coastal zone management, recent Congressional proposals for a comprehensive erosion management program in the U.S. (DAVISON, 1992) are likely to further advance this trend by increasing the financial incentives of beach nourishment.

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ANNOTATED BIBLIOGRAPHY ENTRIES:  
 BEACH NOURISHMENT AS A  
 COASTAL MANAGEMENT TOOL

HALL, J.V., JR. 1952. Artificially Constructed and Nourished Beaches in Coastal Engineering: 1952 Proceedings. New York: American Society of Civil Engineers, *Proceedings of the 3rd Coastal Engineering Conference*, pp. 119–33.

DESCRIPTION: An inventory of beach nourishment projects in the United States between 1922 and 1950 was compiled. Some 72 separate projects or phases of nourishment projects were catalogued, including an assortment of design parameters. Some 12 of these projects were the result of disposal of material dredged for the purpose of harbor construction or navigation maintenance. The vast majority of the projects catalogued by HALL (1952) were located along the New York, New Jersey and Southern California coastlines. The author suggested that basic design parameters for required volume and geometry of borrow material be established.

KEY WORDS: Artificially nourished beaches, New York, New Jersey, Southern California, harbors, dredged spoil.

KRUMBEIN, W.C., 1957. A Method for Specification of Sand for Beach Fills. *Technical Memorandum No. 102*. Beach Erosion Board Corps of Engineers, 43 pp.

DISCUSSION: This paper relied on existing work of the author which described grain size distributions of natural beaches and applied it to the problem of beach fill compatibility. As such, it is one of, if not the first scientific study of beach nourishment. Through statistical methods, KRUMBEIN recognized the adverse consequences of fill incompatibility: too fine—the fill is lost offshore; too coarse—the foreshore is steepened. The optimum beach fill has the same grain size characteristics as the native beach—nature is allowed to sort the composite appropriately.

KEY WORDS: Beach fill, particle size distribution, fill compatibility, composite, log-normal distribution, skewed distribution.

KRUMBEIN, W.C. and JAMES, W.R., 1965. A Lognormal Size Distribution Model for Estimating Stability of Beach Fill Material. *Technical Memorandum No. 16*. U.S. Army Coastal Engineering Research Center, Washington, D.C., 17 pp.

DISCUSSION: This paper addressed the problem of estimating the additional volume of fill required to meet design conditions when the available borrow material is finer than the native sand. A mathematical solution

was presented for cases where the borrow material is not as well-sorted as the native beach sand. Where the borrow material is better sorted than the native material, no mathematical solution was found, and empirical procedures which consider slope adjustments were recommended for determining fill volumes. The mathematical theory assumes lognormality of the particle size distribution. In essence, Krumbain and James defined a “critical ratio” of the amount of borrow material needed to produce a size distribution in the stabilized fill equivalent to the native sand. This critical or overfill ratio became a fundamental beach nourishment design parameter used by the U.S. Army Corps of Engineers for several decades and distinguishes this paper as an important advancement.

KEY WORDS: Beach nourishment, borrow material, grain size distribution, sorting, skewness, native sand, winnowing, lognormal distribution.

CUNNINGHAM, R.T., 1966. Evaluation of Bahamian oolitic aragonite sand for Florida beach nourishment. *Shore and Beach*, 34, 18–21.

DESCRIPTION: CUNNINGHAM (1966) described a test conducted by Union Carbide, Inc. to evaluate the technical and economic feasibility of using oolitic aragonite sand imported from the Great Bahama Bank for beach nourishment in Florida. The author defined the physical properties which make aragonite attractive, including grain size, sphericity, specific gravity, natural adhesion, sorting, color, and availability. About 1,000 tons of aragonite sand and a control group of native beach sand were placed in wind rows on the foreshore in St. Lucie Co., Florida.

RESULTS: The experimental piles were redistributed by wave action during high tides. The project revealed that the aragonite sand remained somewhat more stable on the foreshore than the native sand.

KEY WORDS: Bahamas, St. Lucie Co., Florida., oolitic aragonite, beach nourishment.

DEAN, R.G., 1974. Compatibility of Borrow Material for Beach Fills. *Proceedings, 14th Coastal Engineering Conference*, American Society of Civil Engineers, New York, pp. 1319–1333.

DISCUSSION: This paper notes the growing application of beach nourishment to erosion problems and the need for design methodologies. DEAN considered problems with the KRUMBEIN and JAMES (1965) method which gives unrealistic results if some of the fill is coarser than the native beach sediment. This is because the KRUMBEIN and JAMES method assumes that the fill ultimately develops the same grain size distributions as the native sand. DEAN developed an alternative method which allows for only the fines being lost. While DEAN's method allows the

suitability of potential borrow sites to be evaluated he acknowledged that it is unenlightening as to loss rates.

**KEY WORDS:** Beach nourishment, borrow material, beach fill, grain size, design.

VALLIANOS, L., 1974. Beach Fill Planning—Brunswick County, North Carolina. *Proceedings, 14th Coastal Engineering Conference, American Society of Civil Engineers, New York*, pp. 1350–1369.

**DISCUSSION:** This paper discussed one of the first attempts at a comprehensive engineering design of a beach nourishment project. The author compared the design applied to other beach nourishment projects at this time to 'common land-fill in a stable upland area.' The design process included: (a) definition of the environment; (b) design and cost estimates; and (c) final plan formulation. A number of optimization and probabilistic procedures were also applied to the design. Significantly, a depth of closure of 8.5 meters below mean sea level was a fundamental element in calculating beach fill requirements, including the determination of maintenance requirements. A telephone enquiry with Mr. Tom Jarrett, U.S. Army Corps of Engineers confirms that this project was never authorized, but it stands as an influential paper in design concepts.

**KEY WORDS:** Beach nourishment, design, planning, depth of closure, Brunswick County, N.C.

JAMES, W.R., 1975. Techniques in Evaluating Suitability of Borrow Material for Beach Nourishment. U.S. Army Coastal Engineering Research Center, *Technical Manual No. 60*. 81 pp. Ft. Belvoir, Virginia.

**DESCRIPTION:** The author described two classic techniques for quantitative comparisons of the textural characteristics of borrow material and the native beach material. To calculate the proportional volume of borrow material with grain-size similar to that of the native beach, JAMES developed the Overfill Ratio ( $R_A$ ): the estimated number of cubic meters of fill material required to produce one cubic meter of beach material when the beach is in a condition compatible with the native material. James also advanced a quantitative approach for addressing the long-term maintenance requirements of a nourishment project, entitled the Renourishment Factor ( $R_r$ ): the ratio of the rate at which borrow material will erode to the rate at which natural beach material is eroding. These concepts assume that both the composite native and borrow material distribution are nearly lognormal. This paper represents a major advancement in beach nourishment design.

**KEY WORDS:** Beach fill, grain size distribution, borrow material, maintenance, overfill ratio, renourishment factor.

WALTON, T.L. and DEAN R.G., 1976. Use of Outer Bars of Inlets as Sources of Beach Nourishment Material. *Shore and Beach*, 44, 13–19.

**DESCRIPTION:** The authors used Red Fish Pass (Captive Island) Florida as an example to show the potential for utilizing outer bars of inlets (ebb tidal deltas) as borrow areas for beach nourishment projects. The dynamics of inlet sedimentation and the proportional relationship between outer shoal size and magnitude of sand divergence (localized alongshore transport reversals) was described. The dredging technology necessary to fully utilize outer shoal material was discussed.

**RESULTS:** The authors concluded that removal of sand from ebb tidal deltas can contribute to the stability of the adjacent barrier, not only because of nourishment, but also by causing more uniform refraction patterns and resulting alongshore transport. The use of interior inlet shoals (flood tidal deltas) was disavowed because of the potential that dredging may upset a sensitive sediment equilibrium and cause an increase in the erosion of the adjacent nourished beach. It was estimated that the outer bars of inlets in Florida could supply the state's nourishment needs for approximately 75 years with high quality material although study of the merits of each inlet on a case-by-case basis was encouraged.

**KEY WORDS:** Beach nourishment, outer inlet shoals, alongshore transport, Florida, Red Fish Pass (Captive Island), local reversal, inlet.

CHRISTIANSEN, H., 1977. Economic Profiling of Beach Fills. In: *Proceedings Coastal Sediments '77*. American Society of Civil Engineers. New York, NY, pp. 1042–1048.

**DESCRIPTION:** The purpose of this study was to measure post-storm beach profiles to determine the ideal (equilibrium) profile for shaping nourishment projects. Up to 20 profiles along a 300-mile reach of the German and Dutch North Sea Coast were surveyed after five severe storms during 1973.

**RESULTS:** CHRISTIANSEN (1977) found that, as a function of mean grain size, beaches typically display concave equilibrium storm profiles. A relationship was developed for estimating optimal storm-surge equilibrium beach profiles from mean grain size ( $d_{50}$ ) data. For more optimal and economic beach fill designs, the author advocated that nourished profiles initially be shaped and seasonally reshaped to conform to storm equilibrium-profiles which would minimize erosion of fill during such events.

**KEY WORDS:** Storm equilibrium beach profiles, beach fill, mean grain size, North Sea coast.

**DETTE, H.H., 1977. Effectiveness of Beach Deposit Nourishment. In: *Proceedings Coastal Sediments '77*. American Society of Civil Engineers. New York, NY, pp. 211-227.**

**DESCRIPTION:** DETTE studied the time history of beach profile adjustment and the planform evolution following total placement of 1.0 million m<sup>3</sup> of sand in the configuration of a "groin" within the exposed surf zone at the Island of Sylt in the German North Sea. The author established profiles at a 500 m spacing across the sand groin and along the beach in both directions and made annual surveys for five years after completion. During the monitoring period, two series of unusual storm surges were experienced.

**RESULTS:** Approximately 30% of the borrow material (primarily the size fraction smaller than 0.2 mm) had been elutriated by cessation of pumping, resulting in an initial sand groin volume of 770,000 m<sup>3</sup>. After a 14-month period of initial profile adjustment (reequilibrium), waves had reshaped the material at the placement site into an equilibrium profile. After five years, more than 60% of the borrow material remained within the beach zone in the downdrift area designated for protection, and the profiles in this area had reached equilibrium condition. Yearly loss rates of the "sand groin" were no greater than traditional nourishment methods. Lee-erosion which is customary with hard structures did not occur with the sand groin. DETTE recommended that the sand groin placement method be employed for future renourishment at Sylt but that it be located 1000 m updrift to maximize residence time in the endangered area.

**KEY WORDS:** Beach deposit nourishment, sand groin, Island of Sylt, equilibrium profile, littoral drift.

**HOBSON, R.D., 1977. Sediment Handling and Beach Fill Design. In: *Proceedings Coastal Sediments '77*. American Society of Civil Engineers. New York, NY, pp. 167-180.**

**DESCRIPTION:** The purpose of this study was to quantify the effect of dredging and handling techniques on borrow sediment textural properties. This evaluation was significant because textural changes during transport from the borrow site to the beach can alter predicted project performance. Sedimentologic data from the Rockaway Beach, NY and New River Inlet, NC projects were examined for the in-situ borrow site, within the hopper bin, and at the beach disposal site.

**RESULTS:** At Rockaway Beach, a 10% volumetric loss due to winnowing of finer grain sizes during dredging of the borrow site, filling of the dredge, rehandling of the fill from the barge, and placement on the beach

produced a fill that was coarser and better sorted than the in-situ native sediments. At New River Inlet, handling during transport resulted in a 16% volumetric loss and a coarsening of material by 0.14 mm. Elutriation of fine sediments generally was found to produce coarser and better sorted sediments which tends to improve predicted performance. The author stressed the importance of considering volumetric losses, coarsening, and improved sorting produced by dredging and transport when overfill and renourishment designs are calculated.

**KEY WORDS:** Beach nourishment, borrow site, hopper dredge, handling losses, overfill factor, renourishment factor, Rockaway Beach, NY, New River Inlet, NC.

**KAMPHUIS, J.W. and MOIR, J.R., 1977. Mean Diameter Distribution of Sediment Sizes Before and After Artificial Beach Nourishment. In: *Proceedings Coastal Sediments '77*. American Society of Civil Engineers. New York, NY, pp. 197-210.**

**DESCRIPTION:** Wave tank research on the redistribution of sediment offshore for "summer" and "winter" wave climates was conducted after a nourishment project. After numerous alternating cycles of winter and summer waves, and the development of an equilibrium profile, sand samples were taken. The beach profile (including bar) was then nourished on the winter profile (i.e., immediately prior to the summer season) and five seasonal wave cycles were run, producing an equilibrium profile. The second test entailed smaller (75% reduction) winter and summer waves and proportionally smaller volumes of fill (excluding bar placement). Both surface and body samples along seven profiles were taken after each wave season subsequent to nourishment.

**RESULTS:** The authors found that dynamic equilibrium of sediment sizes is essentially attained in the simulated first year after nourishment. Below a thin surface layer of nourished material the sediment was native across the profile except for some coarse nourishment grains under the face of the bar offshore and finer grains under the berm crest. Very little grain sorting was found at depth indicating mass movement without sorting. The profile and the mean grain size distribution in the thin surface layer with distance offshore were closely related. A change in profile caused by nourishment was quickly followed by a parallel change in mean diameter distribution. The winter wave model transported all sizes offshore without accompanying offshore bar movement. The authors cautioned that for winter conditions attempting to move a bar offshore by nourishment will be unsuccessful without massive offshore placement.

**KEY WORDS:** Beach nourishment, wave tank, winter waves, summer waves, mean grain size, offshore trans-

port, sorting, equilibrium profile, offshore bar, profile equilibration.

**NERSESIAN, G.K., 1977.** Beach Fill Design and Placement at Rockaway Beach, New York using offshore ocean borrow sources. In: *Proceedings Coastal Sediments '77*. American Society of Civil Engineers. New York, NY, pp. 228-247.

**DESCRIPTION:** The purpose of this paper was to describe the sampling, sedimentological analysis, design, and 3-phase construction (1975-77) of the Rockaway Beach, New York nourishment project. The project dimensions were: 6.2 miles length; berm width 100-200 ft. with a 10 ft. elevation; and a lower slope of 1 on 30 and an upper slope of 1 on 20. Borrow site analysis included 45 cores up to 25 ft. and seismic surveys. Surface samples of the native beach sand along 6 profiles extending from the beach berm to -30 ft. depth. Composite native grain sizes for the top of the berm, the tidal zone, and the foreshore zone and the borrow area were computed with sieve analysis. The suitability of the borrow sediments were calculated using both the KRUMBEIN-JAMES (1965) and JAMES (1975) overfill models.

**RESULTS:** The borrow material was smaller than the native with an average overfill ratio of 1.25 when both handling and long-term losses were considered. The selected slopes of the required fill volume either equalled or were greater than volumetric requirements with the 1.25 overfill factor. The scheduling of construction during fair weather conditions (late spring-early fall) allowed minimal dredging disruption due to inclement weather.

**KEY WORDS:** Beach nourishment, borrow sites, overfill ratio, vibracore, beach slope, fill volume, littoral transport, placement timing.

**SCHWARTZ, R.K. and MUSIALAWSKI, F.R., 1977.** Nearshore Disposal: Onshore Sediment Transport. In: *Proceedings Coastal Sediments '77*. American Society of Civil Engineers. New York, NY, pp. 85-101.

**DESCRIPTION:** The purpose of this study was to explore alternative beach nourishment placement techniques by examining whether sand dumped seaward of the surf zone would be effectively transported landward. SCHWARTZ and MUSIALAWSKI monitored the movement of 26,750 m<sup>3</sup> of coarse sand placed by means of a split-hull barge near New River Inlet, NC. Beach/nearshore profiles spaced at 30 m were measured at nearly weekly intervals for 13 weeks.

**RESULTS:** Profile analysis showed that the majority of the sediment was moved landward by natural processes from a depth of 1.8-4.0 m. Once in the innermost littoral zone the fill was deflected by longshore currents and deposited on downcoast beaches. This

was the first study showing the potential of offshore dumping by split-hull barges in the U.S.

**KEY WORDS:** Beach nourishment, profile nourishment, onshore transport, New River Inlet, NC, split hull hopper dredge.

**WALTON, T.L. and PURPURA, J.S., 1977.** Beach Nourishment Along the Southeast Atlantic and Gulf Coasts. *Shore and Beach*, 45, 10-18.

**DESCRIPTION:** WALTON and PURPURA (1977) provided one of the first assessments of beach nourishment projects and nourishment methods in the U.S. Projects in Carolina Beach, NC, Hunting Island SC, Harrison County, MS, and Cape Canaveral Beach, Virginia Key-Key Biscayne, Key West, and Treasure Island, Florida were evaluated and reasons for their relative success discussed. Common reasons for under-performance included undersized borrow material, proximity to inlets, excessive storm activity, and extreme background erosion rates. The authors also evaluated the effectiveness and economics of various nourishment methods including floating barge hydraulic pipelines, hopper dredge pump-out, offshore dumping, and beach scraping. Based on poor performance, the authors discouraged offshore dumping and scraping. Hopper dredges and hydraulic pipelines were judged to be the most promising methods. However, the pipeline method is normally very costly and vulnerable under inhospitable wave climates and the hopper dredge method is limited by a paucity of pump-out machinery in the U.S.

**KEY WORDS:** Beach nourishment, offshore dumping, beach scraping, borrow site, hopper dredge, background erosion, loss rates.

**HALLERMEIER, R.J., 1981.** A Profile Zonation for Seasonal Sand Beaches from Wave Climate: *Coastal Engineering*, 4, 253-277.

**DESCRIPTION:** HALLERMEIER collected existing sand characteristics ( $y'$ ,  $D$ ) and statistics of annual wave climate ( $H$ ,  $\sigma$ ,  $T$ ) from four Atlantic Coast, five Gulf Coast, and 11 Pacific Coast sites. This data was applied to two equations defining critical values of Froude numbers for sediment suspension energetics and wave induced sand motion on the bed.

**RESULTS:** A model was developed that divides the shore-normal profile of a seasonal sand beach into three submarine zones parallel to the shoreline. The "shoal zone" was defined as the buffer region between the active littoral zone and the offshore zone where expected surface waves have neither strong nor negligible effects on the sand bottom during a typical year. The shoal boundaries were defined as extending seaward from the maximum depth for erosive cutting of the nearshore by yearly extreme waves (i.e.,  $d_e$ ) to the maximum water depth for sand motion initiation

by the yearly median wave condition ( $d_s$ ). The author concluded that suitable material for nourishment of the nearshore profile must generally be placed landward of  $d_s$ . This represents a classic paper in the present understanding of the seaward limit of the active beach profile (closure depth) and is fundamental to the design of beach nourishment projects.

**KEY WORDS:** Closure depth, littoral zone, shore-normal profile, beach nourishment, offshore zone, wave climate.

**MARSH, G.A. and TURBEVILLE, D.B., 1981.** The Environmental Impact of Beach Nourishment: Two Studies in Southeastern Florida, *Shore and Beach*, 49, 40–44.

**DESCRIPTION:** The purpose of this study was to quantitatively assess the density and diversity of benthic invertebrates within the borrow area and from undisturbed adjacent bottoms for two nourishment projects in Hallandale (1971) and Hillsboro Beach (1972), Florida. Samples from three control stations located at 100 m intervals were compared with samples within the pit for the Hillsboro project. After initial sampling in June, 1977, two control and borrow stations were sampled at quarterly intervals for one year. For the Hallandale project, five soft and four reef stations along a cross-shore transect were sampled in 1977. A control transect with equivalent stations was established 900 m to the south.

**RESULTS:** Samples from the Hillsboro Beach project revealed that five years after dredging there was no reduction in numbers of individuals, number of species, or in species diversity. For the Hallandale transects, sandy-bottom samples along both transects showed a pronounced increase in both numbers of species and individuals at greater depths. Reef fauna also showed an increase in abundance and diversity at greater depths along both transects. Although no long-term adverse effects of beach nourishment were reported by the authors, they cautioned that findings do not imply that offshore dredging should be indiscriminately undertaken everywhere, and that damage to benthic fauna can occur, especially near coral reefs as has been reported in other studies.

**KEY WORDS:** Benthic invertebrates, borrow area, post-nourishment monitoring, sandy bottom fauna, reef fauna.

**PEARSON, D.R. and RIGGS, S.R., 1981.** Relationship of Surface Sediments on the Lower Forebeach and Nearshore Shelf to Beach Nourishment at Wrightsville Beach, NC. *Shore and Beach*, 49, 26–31.

**DESCRIPTION:** Wrightsville Beach, NC has been nourished on five occasions from 1939–1970, predominantly with fine-grained, gray-black material from a

local estuarine source. PEARSON and RIGGS (1981) analyzed vibrocore, seismic, and volumetric data and sedimentological characteristics of six surface samples from the lower forebeach and nearshore shelf off Wrightsville Beach.

**RESULTS:** As a result of using borrow material finer than that of the natural beach, nourishment projects at Wrightsville Beach have experienced severe erosion. The authors conclude that the majority of the estuarine beach nourishment sediments were transported offshore during high energy storm events and deposited on the lower beachface and nearshore shelf beyond closure depth.

**KEY WORDS:** Wrightsville Beach, beach nourishment, offshore losses, grain size compatibility, estuarine sediments.

**OLSEN, E.J., 1982.** South Seas Plantation Beach Improvement Project. *Shore and Beach*, 50, 6–10.

**DESCRIPTION:** The author described a plan for private financing of beach nourishment at Captiva Island, Florida in 1981 as a viable alternative to public financing. Such schemes are likely to be increasingly utilized in the future because of greater competition for State and Federal funds and cost-increases associated with delays in obtaining government funding. Highlights of the Captiva financing scheme included cost sharing by all property owners, prorated fees based on distance from the shoreline and footage of beach frontage, and tax deductible and extended payment plans.

**KEY WORDS:** Private financing, tax deductible, cost proration plan, Captiva Island, Florida, inlet dynamics.

**SALOMAN, C.H., NAUGHTON, S.P. and TAYLOR, J.L., 1982.** Benthic Community Response to Dredging Borrow Pits. Panama City Beach, Florida. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Ft. Belvoir, Virginia, *Miscellaneous Report No. 82-3*, 138 pp.

**DESCRIPTION:** The authors studied offshore borrow areas used in a beach nourishment project at Panama City Beach, Florida. The repopulation of soft-bottom fauna located in 3–5 m deep pits was compared to data obtained for a control group in 9 m of water.

**RESULTS:** The authors found a small decrease in the diversity of sand fauna species. Species recovery began immediately after completion of dredging activities with full completion taking approximately one year. An increase in silts and clays and organic material after dredging did not significantly change the make up of the benthic community, but may have increased the richness of the fauna species.

KEY WORDS: Beach Nourishment, Panama City Beach, Florida, borrow areas, species recovery.

CHOU, I.B., POWELL, G.M. and WINTON, T.C., 1983. Assessment of Beach Fill Performance by Excursion Analysis. *Proceedings Coastal Zone '83*. San Diego, California. American Society of Civil Engineers. New York, NY, pp. 2361-2377.

DESCRIPTION: From 1964 to 1975, 1,601 repetitive beach surveys were recorded at 50 profile stations at Wrightsville Beach, North Carolina. Mathematical description of post-nourishment performance allowed excursion distance time series data to be calculated. Volumetric trends of the nourished beach were determined for both short-term (seasonal) and long-term periods.

RESULTS: Temporal resolution (survey frequency and timing) was found to be as important as spatial resolution (profile spacing) in beach nourishment monitoring. Data indicated that the geomorphic response of nourished beaches should be divided into three phases for monitoring purposes: long-term loss; seasonal variation; and exponential initial loss (reequ岸ilibration period). The nourished profile readjusted rapidly during the first six months. After 9-12 months essentially all initial losses due to profile reequilibrium and sorting had occurred. After 12 months the upper beach face retreated at a constant slope. Edge excursions (end losses) were significant immediately after placement. The SPM fill factor predicted a 60% initial loss due to sorting and post-fill grain-size data implies that 66% was actually lost due to sorting. However, other factors such as profile readjustment and end losses were also found to be significant. The rapid rate of loss was probably exacerbated by increased wave attack due to misalignment of the initial beach planform, the proximity and interaction of inlets, and location of the project in an area of high historical erosion rates.

KEY WORDS: Beach nourishment, Wrightsville Beach, NC, profiles, monitoring, excursion distance, end losses, planform misalignment, inlet, sorting, initial losses, beach fill, seasonal variation, profile readjustment.

DEAN, R.G., 1983. *Principles of Beach Nourishment*. In: P.D. KOMAR, ed., *CRC Handbook of Coastal Processes and Erosion*. CRC Press Inc. Boca Raton, Florida.

DESCRIPTION: The pathways of sand transport from a nourished beach through suspension of fine grains, profile adjustment, and end losses was described. Quantified examples of the relevance of grain size and equilibrium beach profiles in beach nourishment projects was provided. The importance of beach fill length on the life of a nourishment project was shown through

the development of a square law relationship. It was demonstrated that the effect of doubling the wave height was to decrease project life by 17.7%. The concept of rapid profile reequilibrium in the first few months after project completion was advanced as was the need to inform and educate the public on this phenomena. A quantitative method was demonstrated for calculating the effect of sea level rise on the maintenance requirements of beach nourishment projects. Citing studies of compressed marsh deposits through loading, the author believes that the additional weight of the new sand can significantly affect loss rates and maintenance requirements of projects where shallow organic strata underlie barrier islands.

KEY WORDS: Beach nourishment, sediment transport, equilibrium beach profile, end losses, inlets, sea level rise, marsh compressibility.

REILLY, F.J. and BELLIS, V.J., 1983. The Ecological Impact of Beach Nourishment with Dredged Materials on the Intertidal Zone at Bogue Banks, North Carolina. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Ft. Belvoir, Virginia, *Miscellaneous Paper 83-3*.

DESCRIPTION: The purpose of this study was to monitor the biological and physical impacts to the intertidal zone associated with a beach nourishment project at Bogue Banks, NC. The borrow sediments for this project were dredged from a neighboring inland harbor and included a significant amount of fines laden with hydrogen sulfide.

RESULTS: REILLY and BELLIS (1983) documented significant suspended sediment concentrations in the intertidal zone and further offshore due to the undersized nature of the fill compared to the native beach material. The high degree of turbidity caused large-scale benthic macroinvertebrates habitat modification and thus epidemic fatalities in both the intertidal zone and areas offshore where the species overwintered. For a period of six months during dredge disposal there was no detection of dominant macroinvertebrates and recovery was generally slow and did not start until construction ended.

KEY WORDS: Beach nourishment, biological impacts, grain size, turbidity, Bogue Banks, NC.

U.S. ARMY CORPS OF ENGINEERS, 1984. *Shore Protection Manual*. 2 Vol. Coastal Engineering Research Center, 4th edition. Washington: U.S. Government Printing Office, Publication #008-002-00218-9. 1307 pp.

DESCRIPTION: The *Shore Protection Manual* (SPM) provided the most comprehensive treatise on coastal

erosion control to date (1991), including several aspects of beach nourishment. Special emphasis was placed on planning criteria for nourishment projects, including longshore transport analysis and native beach and borrow site sedimentologic characterization. Quantitative models used to describe the overfill and renourishment factors were detailed, along with example problems to demonstrate the application of these models. Design considerations for cross-shore slopes, planform geometry, and feeder beach location were outlined. The advantages, disadvantages, and limitations of hopper dredges with pump-out capability and the hydraulic pipeline dredge were outlined. The design, construction, performance, and maintenance of the Carolina Beach, NC, Redondo Beach, CA, and Dade County, Florida, nourishment projects were summarized as representative examples of nourishment projects in the U.S.

**KEY WORDS:** Beach nourishment, hopper dredge, hydraulic pipeline dredge, borrow site, native beach, grain size, renourishment factor, overfill factor, feeder beach, stockpile.

**BRUUN, P., 1986.** Sediment Balances (Land and Sea) with Special Reference to the Icelandic South Coast from Torlakshofen to Dyrholarey. River Nourishment of Shores—Practical Analogies on Artificial Nourishment. *Coastal Engineering*, 10, 193–210.

**DESCRIPTION:** BRUUN (1986) discussed the advantages of nourishing the entire profile versus just the subaerial portion of the beach. The author advocated nourishing the profile as a whole in its equilibrium shape, thereby avoiding both rapid transversal and longshore losses due to an unnatural steep profile. He also encouraged the use of tracer experiments to determine the depth at which it is practical and economic to place material of a particular grain size. The use of a range of grain sizes fining in a seaward direction was promoted for economic reasons and to offset common shortages of medium and coarse material.

**KEY WORDS:** Beach nourishment, profile nourishment, grain size, equilibrium profiles, tracer experiments, longshore transport.

**STAUBLE, D.K. and HOEL, J., 1986.** Physical and Biological Guidelines for Beach Restoration Projects: Part II-Physical Engineering Guidelines. *Report Number 77*. Gainesville: Florida Sea Grant College. 100 pp.

**DESCRIPTION:** The objective of this manual was to design and present performance monitoring standards for the 1) borrow area 2) the nourishment area, and 3) the littoral environmental conditions during pre-construction, construction, and post-construction

phases of beach nourishment projects. This represents the most comprehensive treatise on all aspects associated with the monitoring of beach nourishment projects. The problems associated with a general lack of performance and environmental monitoring for completed beach nourishment projects was outlined. An inventory was made of some 12 completed nourishment or sand by-pass projects where at least limited monitoring information was collected. All but one of these projects was located in the State of Florida. From this inventory, objective guidelines for monitoring and standardization of monitoring procedures were developed. The authors argued that systematic project performance monitoring will result in improved and expedited permitting procedures and savings in the design and labor cost associated with project delays. An accuracy comparison of the three prevalent beach fill models was made.

**RESULTS:** The examination of numerous past beach restoration and inlet bypassing projects (mostly in Florida) revealed a distinct lack of monitoring and compilation of field data on project performance and its resulting biological impact. Of the limited monitoring information supplied for the projects, no standardization of format, content, reporting periods, or data analysis and presentation was evident. An encouraging trend for the most recent nourishment projects in Florida, however, showed a requirement for both pre- and post-construction aspects. The majority of the nourishment projects reviewed were located at erosion sites in close proximity to or downdrift of inlets. The authors recommend a detailed topographic/bathymetric survey schedule along established profiles as follows: 1) Pre-nourishment, 2) immediate post-fill, 3) three, six, nine and 12 months in the first year, 4) 18 and 24 months in the second year, and 5) 36 month. Although costly, the Indialantic/Melbourne Beach nourishment project showed that collecting profile data in the immediate post-fill phase can yield insights into the rapid profile readjustment (reequilibrium) period. Immediate post-fill surveys and those taken after full project completion revealed significant disparities. The authors recommend surveying immediately after nourishment on each individual profile. Of beach fill models evaluated, the Adjusted Shore Protection Manual Method (JAMES, 1975) generated the best calculation of actual fill behavior, provided that a safety factor was used. Based on the projects studied the authors discovered that material smaller than 3 Phi was winnowed from the project area. Thus for applying the Adjusted SPM method, a safety factor of 3.0 Phi gave the best results. For sampling the native beach and borrow area the use of composite samples was shown to remove variability in sediment distribution across these areas. Renourishment Factor calculations using computed delta values (JAMES, 1975) gave the best match to actual fill behavior.

KEY WORDS: Florida, Jacksonville District Corps of Engineers, Beach Nourishment, sand bypass, monitoring, standardization of monitoring, project performance monitoring, environmental impact monitoring, beach fill models, profile reequilibration.

WEGGEL, J.R., 1986. Economics of Beach Nourishment Under Scenario of Rising Sea Level. *Journal of Waterway, Port, Coastal and Ocean Engineering*, 112, 418-427.

DESCRIPTION: With increasing rates of sea level rise, the author quantifies future cost increases for beach nourishment projects based on decreases in the periods between successive maintenance fills. For perpetual and finite lifetime projects and variable interest rates, the author analyzes the value of beach nourishment under low (1.8 ft. by 2100) and mid-range (4.6 ft. by 2100) sea level rise scenarios. WEGGEL (1986) concludes that "if projections of an increasing rate of rise are correct, it will become increasingly difficult to economically justify future beach nourishment projects." As the cost of suitable fill increases with sea level rise, it was further concluded that hard engineering works will become more economical if those structures increase residence time of nourishment sand.

KEY WORDS: Beach nourishment, sea level rise, coastal structures, economics, renourishment periods.

ASHLEY, G.M., HALSEY, S.D. and FARRELL, S.C., 1987. A Study of Beach Fill Longevity: Long Beach Island, New Jersey. In: *Proceedings Coastal Sediments '87*. American Society of Civil Engineers. New York, NY, pp. 1188-1202.

DESCRIPTION: ASHLEY *et al.* (1987) conducted one of the few long-term (seven years) beach nourishment monitoring programs on the northern end of Long Beach Island, NJ adjacent to Barnegat Inlet. Monitoring consisted of LEO data, sand sampling, and 11 profiles across both nourished and control sections. Monitoring began five months prior to emplacement, was maintained for four months during construction, continued biweekly for three years, and annually to year seven. Fill was dredged from Barnegat Inlet and was compatible with the native material (0.4 mm).

RESULTS: Based on beach slope and volume change, nourished and unnourished beaches responded similarly under a spectrum of storm and fair weather conditions. Fill placed on the inlet side of the nodal point of a local longshore current reversal rapidly moved back into the inlet and was lost in an intrajetty area. Because of the immediate transport of material back into the inlet, the authors stressed the need to investigate the nature of the sediment and

local longshore current patterns before nourishment designs are chosen.

KEY WORDS: Beach nourishment, monitoring, local reversal, nodal point, grain size, inlet, Long Beach, NJ.

COMBE, A.J. and SOILEAU, C.W., 1987. Behavior of Man-Made Beach and Dune, Grand Isle, Louisiana. In: *Proceedings Coastal Sediments '87*. American Society of Civil Engineers. New York, NY, pp. 1232-1242.

DESCRIPTION: The authors described the design and performance of a beach nourishment/artificial dune project on Grande Isle, Louisiana under repetitive hurricane and winter storm conditions. The \$8,640,000 project was 7.5 miles in length, required 2,800,000 yd<sup>3</sup> of fill, including a 11.5 ft. dune to provide 50-year storm protection. The design fill section used a 1 on 33 slope based on the naturally occurring beach and dune cross-section. Hydraulic pipelines were used to fill segmented compartments constructed from parallel dikes. Fill was obtained from two offshore borrow areas located a-a mi. from the beach and within closure depth. The borrow site was dredged in a dumb-bell shape with the centroids of the bells considerable deeper than the middle portion.

RESULTS: After several winter storms, two cusped bars formed in the lee of the borrow area. Predominant erosion (8% of volume) occurred immediately adjacent to and between the cusped bars which proved to be stable features. Three hurricanes in 4 months in 1985 eroded 70,000, 40,000 and 370,000 yd<sup>3</sup> of fill, respectively. The offshore borrow areas were of sufficient size and depth to modify wave climate (refraction) during storms. One year after the storms, borrow pits showed in-filling to about half depth in the deeper areas and complete filling in the remainder.

KEY WORDS: Beach nourishment, artificial dune, borrow site, hurricane, cusped bar, Grande Isle, Louisiana, wave refraction.

DEAN, R.G., 1987. Realistic Economic Benefits from Beach Nourishment. In: *Proceedings Coastal Sediments '87*. American Society of Civil Engineers. New York, NY, pp. 1558-1572.

DESCRIPTION: The author presented a simple method and illustrated examples to quantify storm damage reduction and recreational benefits in and adjacent to beach nourishment projects. The method was based on a proportional damage curve for upland structures as a function of beach width and storm return period. Diametric cases were considered whereby all nourishment material either remained or left the project area over time. Monte Carlo simulation was used for



15 cases of project length, wave height, added beach width, and interest rates.

**RESULTS:** DEAN (1987) advanced the concept that the greatest benefits are realized for beaches that are initially narrow (i.e., where structures are at greatest risk). He also promoted the concept that sand removed from the project area and deposited in adjacent downdrift areas provides continued benefits. With time, as nourishment material was removed from the project area and deposited in adjacent areas, a net gain in benefits occurs when both areas are considered. The factors important to quantification of relative benefits to each area are fill length, wave height, longshore transport coefficient, fill width, and interest rates. Example calculations showed that benefits to adjacent areas can be significant relative to those in the project area. The author concluded that objective assessments of nourishment projects must acknowledge the benefits from sand transported from the placement area to adjacent areas.

**KEY WORDS:** Beach nourishment, benefits, longshore transport, storm damage reduction, recreation, project adjacent areas, beach width, storm frequency, Monte Carlo simulation.

**DELFT HYDRAULICS, 1987. *Manual on Artificial Beach Nourishment.*** Centre for Civil Engineering Research, Codes and Specifications, Rijkswaterstaat, Report 130.

**DESCRIPTION:** A comprehensive overview of various matters related to beach nourishment, including a thorough literature survey, were presented. A description of the various models and design aspects of beach nourishment and a summary of significant projects world-wide were provided. Based on the recorded performance of these completed projects the predictive value of existing mathematical models were assessed. Exercises with one-line and two-line coastal models were made for nourishment projects on the island of Ameland and Sylt and near the cities of Flushing (Vlissingen) and Zeebrugge. The relative merit of execution and placement methods were discussed. Issues related to construction from a dredging contractor's perspective were provided. This includes a discussion of methods for quality control and reliability analysis. Potential environmental impacts associated with all phases of nourishment were evaluated.

**RESULTS:** It was found that generally nourishment is a cost-effective and technically feasible method for protecting coastal areas and maintaining recreational beaches. An integral design method for nourishment, including all relevant parameters is not yet available, although adequate models for predicting separate responses of nourishment projects do exist. For coasts with typical bathymetry and wave climate a one-line

model accurately predicted project response. Two-line models also provided reasonably accurate results for the beach and inshore of Sylt and Zeebrugge. In general, subaerial placement of material (beach nourishment) was favored over subaqueous placement (profile nourishment). There is a lack of adequate monitoring in both pre- and post-project periods and a lack of standardization in monitoring that has been performed. Inadequate monitoring has in turn made it difficult to develop new models and perfect existing ones. For consistent and accurate assessment of nourishment projects the authors recommended that clear and objective definition of sediment losses should be developed. Losses should be quantified volumetrically and measured from the entire active beach system (i.e., to closure depth). Sand transported alongshore out of the immediate project area should receive credit as being beneficial to the downdrift coast. Customarily, it was found that negative environmental impacts of beach nourishment schemes are limited or minimal when uncontaminated material is dredged. Adverse effects can be significantly reduced by avoiding deeply dredged borrow pits and biologically sensitive areas. The optimal time for nourishment, from a biological standpoint, was the winter season when fisheries reproduction is minimal. It was envisaged that nourishment will be utilized with increasing regularity in the future and as such suitable borrow sites will become more difficult to locate.

**KEY WORDS:** Beach nourishment, quality assurance, environmental impacts, borrow area, monitoring program, grain size, Sylt, Zeebrugge, equilibrium profile, nourishment design, planform evolution, one-line and two-line models, project assessment.

**GROVE, R.S., SONU, C.J. and DYKSTRA, D.H., 1987. Fate of Massive Sediment Injection on a Smooth Shoreline at San Onofre, California. In: *Proceedings Coastal Sediments '87.*** American Society of Civil Engineers. New York, NY, pp. 531-538.

**DESCRIPTION:** The purpose of this study was to observe the sediment transport processes associated with the instantaneous disengagement of a 200,000 yd<sup>3</sup> sand "hump" to the San Onofre beach system. Six cross-shore profiles were established up to 9,000 m downdrift and 19 surveys were made over a two year period.

**RESULTS:** The hump migrated slowly (2 m/day or 1 km/yr), underwent rapid decay (50% size reduction every 300 days or by 1/3 per km), and the influence of this quantity of sediment became negligible after a few years. The migrating sand protrusion simulated a groin hump and was preceded by an erosion wave which was most prevalent in the subaqueous profile. The length of the migratory erosion wave was disproportionately large compared to the accretion wave.

The authors concluded that beyond some critical distance downcoast that beaches may experience only the effect of the erosion wave, diametrical to the intent of stockpile nourishment.

**KEY WORDS:** Longshore transport, erosion wave, cross-shore profile, sand hump, Southern California.

LUDWICK, J.C., KANG, H.J. and REYNOLDS, R.N., 1987. Loss of Filled Sand from an Estuarine Groin System. In: *Proceedings Coastal Sediments '87*. American Society of Civil Engineers. New York, NY, pp. 1158-1173.

**DESCRIPTION:** LUDWICK *et al.* monitored the cross-shore and longshore movement of 10,000 m<sup>3</sup> of borrow material placed in a test compartment of a groin field at Willoughy Spit, VA. This was the first comprehensive monitoring of groin-contained beach fill for the expressed purpose of developing predictive models of fill-life and seeking alternatives to prolong groin-contained nourishment projects. The volumetric time-history of the compartment was developed from 26 surveys of beach topography and shoreface bathymetry made over a 3-year period.

**RESULTS:** Long-term movement of sand in the fill compartment was dominated by groin overtopping in an alongshore direction. Seasonal patterns also indicated strong sediment redistribution within the compartment. The authors identified two primary zones of shorewise beachfill transfer: 1) a nearshore/swash, wave-dominated zone where intra-compartment transfer occurs by groin over-topping during periods of superelevated water; 2) a zone beyond the ends of groins where sediment driven by tidal currents skirts groin ends. The additional height of the fill lessens the effective elevation of existing groins. The importance of this process decreases with time as fill is lost from a compartment. A mathematical model to predict the effective life of beach fill placed in groin fields was developed. To increase effective life, the authors suggested adding T-heads to groins to inhibit offshore losses and increasing groin elevations to reduce over-topping and thus alongshore losses.

**KEY WORDS:** Beach fill, groin compartment, groin field, reequilibration, alongshore transport.

MOLLER, J.P. and SWART, D.H., 1987. Extreme Erosion Event on an Artificially-Nourished Beach. In: *Proceedings Coastal Sediments '87*. American Society of Civil Engineers. New York, NY, pp. 1158-1173.

**DESCRIPTION:** The coastal erosion problems on the Danish North Sea coast in the area of Hurdle Sande and Argab were described. Three beach nourishment models of the Danish Hydrographic Office (Kystin-

spektoratet) to stabilize the coastline under various statistical risks (storm frequencies) were discussed. Model 1 offered "total protection" and is unlimited with regard to time with a statistical risk of penetration by storm surge of less than 1 in 100 years. Model 2 offers "long-term" (60 yr.) protection with a maximum retreat rate of 0.8 m/yr. and after 25 years penetration risk is less than 1 in 100 years; after 35 years, 1 in 50 years. Model 3, a "relatively long-term" (40-50 yr.) solution, with a maximum retreat rate of 2 m/yr. and after 10 years penetration risk is below 1 in 100 years; after 35 years, 1 in 50 years.

**RESULTS:** Beginning in 1973-74 with sand dredged from outlets and harbors and continuing in the 1980s with offshore dredging, approximately 1.5 million m<sup>3</sup> of sand has been placed on this beach. Future annual nourishment cost for model 1 was 13 million Danish Crowns; model 2, 3.5 million; and model 3, 1.2 million. With the higher risk of flooding, model 1 was considered the only acceptable long-term solution, despite funding and political difficulties. MOLLER (1987) advocated continuous nourishment with sand dredged from beyond closure depth and dumped at 4-5 m depth.

**KEY WORDS:** Beach nourishment, Denmark, beach erosion, statistical risk, flooding, dune, inlets, long-shore transport.

PILKEY, O.H. and CLAYTON, T.D., 1987. Beach Replenishment: The National Solution? American Society of Civil Engineers: *Proceedings of Coastal Zone '87 Conference*, New York, NY, pp. 1408-1419.

**DESCRIPTION:** The purpose of this article was to evaluate the success of designs in predicting the durability and cost of beach nourishment projects along the East Coast of the U.S. Data were collected for 90 beach segments and 200 fill placements from federal, state, and local government publications and unpublished file data, Congressional documents, publications from symposia and journal articles, consultants reports, and media accounts. Parameters evaluated included costs, volumes placed, monitoring results, and renourishment frequencies. Interpretations of data on 17 nourished beaches, were presented to demonstrate the variability among parameters.

**RESULTS:** PILKEY and CLAYTON (1987) concluded that monitoring data kept on projects was haphazard and not standardized, making meaningful quantitative comparison of design versus performance difficult. The majority of designs were found to underestimate project lifespans and costs. The primary factor for project underperformance was construed to be storms. The influence of design parameters such as grain size, beach length, equilibrium profiles, and overfill and renourishment models were considered

of questionable utility. The authors suggested an empirical approach to nourishment instead of engineering designs and more frequent renourishment instead of single major placements.

**KEY WORDS:** Beach replenishment, East Coast, monitoring, project cost, renourishment, storms, project lifespan, design models.

**THOMPSON, C.L., 1987.** Beach Nourishment Monitoring on the Great Lakes. In: *Proceedings Coastal Sediments '87*. American Society of Civil Engineers. New York, NY, pp. 1203–1215.

**DESCRIPTION:** A coordinated monitoring system is currently employed in the Great Lakes by the Detroit District USACE. This system uses pre- and post-placement vertical aerial photography and photogrammetric mapping, hydrographic and topographic surveys, sediment sampling and analysis, and miscellaneous data such as still photographs and videotapes to fill gaps between sampling periods. The concurrent coordination of sampling times for these primary data sources, a reliance on personal computer software for data analysis, and monitoring of adjacent control (non-nourished) areas to determine background erosion, are important elements of the Detroit District monitoring program.

**BACA, B.J. and LANKFORD, T.E., 1988.** *Myrtle Beach Nourishment Project: Biological Monitoring Report—Years 1, 2, 3*. Report to City of Myrtle Beach; Coastal Science & Engineering Inc., Columbia, South Carolina. 50 pp.

**DESCRIPTION:** BACA and LANKFORD (1988) investigated the biological impacts associated with a beach nourishment project in Myrtle Beach, SC where sand was mined from inland sites and trucked. Intertidal and subtidal macrobenthic communities were sampled quarterly at the nourished site and control sites.

**RESULTS:** Following project completion species richness declined but rapidly (weeks) recovered and after 3–4 months actually exceeded numbers at control sites. The authors attribute the modest impacts and rapid recovery to the high compatibility of the inland sediments with the native beach material and the timing of the nourishment to winter/early spring.

**KEY WORDS:** Beach nourishment, trucking, biological impacts, Myrtle Beach, SC.

**BLACK, D.E., DONNELLEY, L.P. and SETTLE, R.F., 1988.** An Economic Analysis of Beach Renourishment for the State of Delaware. University of Delaware Department of Economics. Unpublished Preliminary Report Submitted to The Department of Natural Resources and En-

vironmental Control, Division of Soil & Water Conservation. Newark, Delaware.

**DESCRIPTION:** An economic analysis of the cost and benefits of a proposed beach nourishment project along coastal Delaware was performed. "Direct" benefits from nourishment included protection of oceanfront property and reduced beach congestion. "Expenditure" benefits included wages for project labor (e.g., truck driver employment) and increased economic activity stimulated by the project (e.g., increased beach visitors). State and local tax revenues were projected to increase both during and after construction due to increased property values and other factors. Eventual losses in tax revenue from casualty loss deductions caused by storm damage would be negated. Direct costs of nourishment included road damage from truck trips, highway congestion, and environmental costs (also associated with pumping).

**RESULTS:** The authors determined the B-C ratio for trucking to be 3.9 versus 2.3 for dredging and hydraulic pipeline transport. State and county tax benefits resulting from the project were calculated to be 17% of the cost of trucking and 6% of dredging. Beachfront property values were believed to devalue by 3% annually due to the threat of erosion. With the nourishment project, the value of beachfront property would increase by 21%.

**DEAN, R.G., 1988.** Recommended Modifications in Benefit/Cost Sand Management Methodology. *Shore and Beach*, 56, 13–19.

**DESCRIPTION:** Dean stressed that Federal policy allowing the removal of high quality sand from navigation entrances and disposal beyond the active profile (closure depth) was an unnecessary waste of a valuable resource. He maintained that the long-term erosional and environmental cost of this practice far outweigh the short-term savings gained by convenient disposal. DEAN also challenged the traditional methods of quantifying the benefits of beach nourishment projects by the amount of material that remains on the subaerial portion of the beach within the immediate project area. Calculations showed that the storm reduction and recreational benefits received in downdrift areas can be incrementally greater than the benefits within the project area. It was proposed that benefits received in down-drift areas be recognized and quantified and that the recipient communities bear a portion of the project cost.

**KEY WORDS:** Beach nourishment, offshore disposal, storm damage reduction, recreational benefits, Florida, project assessment.

**MACINTOSH, K.J. and ANGLIN, C.D., 1988.** Artificial Beach Units on Lake Michigan. In: *Proceedings 21st International Coastal Engi-*

neering Conference, Malaga, Spain. American Society of Civil Engineers, New York, NY, pp. 2840–2854.

**DESCRIPTION:** The purpose of this paper was to describe the design and performance of four artificial beach fill projects constructed on Lake Michigan as a result of 1985–1986 high lake levels. The project design entailed creation of beach fill units stabilized by in echelon offshore breakwaters connected to the beach by groins. The primary purpose of the projects was erosion control; the secondary purpose, recreation. Two types of beach fill materials were utilized: 1) Waste material (0.1 mm–80 mm;  $D_{50} = 3$  mm) from a nearby tunnelling project for two projects and 2) coarse ( $D_{50} = 2.6$  mm) sand from the other two projects. When projects were subjected to severe winter storms they performed as predicted by the design models. Post-project monitoring revealed that nourished material was stable and described by the authors as “extremely successful.”

**KEY WORDS:** Artificial beach fill, breakwaters, groins, Lake Michigan, erosion control, fill material, grain size, beach profiles.

**PILKEY, O.H., 1988.** A “Thumbnail Method” for Beach Communities: Estimation of Long-Term Beach Replenishment Requirements. *Shore and Beach*, 56, 23–31.

**DESCRIPTION:** PILKEY (1988) used data collected by PILKEY and CLAYTON (1987) on 200 East Coast beach nourishment projects to evaluate estimates of long-term volume requirements for maintaining the project dimensions. Based on this data, the author suggested a method for estimating the long-term volume requirements of new and large (250,000 yds<sup>3</sup>/mi) nourishment projects on the East Coast. The method was based on project design life, initial nourishment volume, and the following regionally variable renourishment intervals: Florida (9 yrs), New Jersey (3 yrs), remainder (5 years). PILKEY’s (1988b) method generally calculated volumetric requirements in excess of those predicted by traditional renourishment predictions.

**KEY WORDS:** Beach nourishment, renourishment maintenance, volume, East Coast U.S.

**SORENSEN, R.M., DOUGLASS, S.L. and WEGGEL, J.R., 1988.** Results from the Atlantic City, NJ Beach Nourishment Monitoring Program, 1988. In: *Proceedings 21st International Coastal Engineering Conference*, Malaga, Spain. American Society of Civil Engineers, New York, NY, pp. 2806–2817.

**DISCUSSION:** The design and construction aspects, monitoring strategy, and monitoring results of the

1986 Atlantic City, NJ beach nourishment project were presented. Results were compared to the performance of earlier Atlantic City fill projects in 1963 and 1970 and their differences discussed. Monitoring included pipeline and beach sediment sampling, wave observations, and beach profiling. Twelve profiles to wading depth were surveyed on a monthly basis for 19 months following pumping and a hydrographic survey was conducted four months before construction.

**RESULTS:** The major difference in the behavior of the 1986 fill and the 1963 and 1970 fills was a reduced rate of loss of material above MSL, north of a nodal point near the Absecon Inlet. Reasons given for this improved performance include better quality of sand fill; a less steep fill profile on the beach face; milder wave climate; and groin and pier construction. Improved fill retention adjacent to the inlet was predominantly due to the improvement of shore-perpendicular structures which prevented alongshore transport to the inlet. Jetties, groins, and piers were found to significantly improve the retention of the beach fill. The authors recommend more frequent, less voluminous fill operations over large volumes and longer renourishment intervals.

**KEY WORDS:** Beach nourishment, inlets, longshore transport, local reversal, groins, jetties, piers, grain size, nodal point, monitoring, cross-shore profiles.

**CLAYTON, T.D., 1989.** Artificial Beach Nourishment on the Pacific Shore: A Brief Overview. American Society of Civil Engineers: *Proceedings of Coastal Zone '89 Conference*, New York, NY, pp. 2033–2045.

**DESCRIPTION:** This was an historical overview of 30 beach nourishment projects on the U.S. Pacific Coast constructed since 1929. Data were collected from published and unpublished materials, personal interviews, and media accounts. Common and unusual features of each project were described.

**RESULTS:** Approximately 200 million yds<sup>3</sup> of borrow material has been placed on Pacific coast beaches since 1929. Onshore borrow sites (e.g., dunes, excavation from construction sites, harbor construction, inshore dredging) and inlet bypassing are utilized more often on the west coast as compared to the East and Gulf Coasts. Direct (subaerial) beach placement and stockpiles are also common placement techniques. Clayton bemoaned the general lack of reliable, quantitative monitoring data on the U.S. Pacific Coast. Offshore (artificial bar) placements generally did not migrate onshore. Downcoast migration of fill as an erosion/accretion wave and rapid erosion initially after placement and eventually a reduced erosion rate were other noteworthy features.

**KEY WORDS:** Beach nourishment, California, offshore placement, sand waves, groins, monitoring, inlet bypassing, harbor dredging.

DEAN, R.G. and GRANT, J., 1989. *Development of Methodology for Thirty-Year Shoreline Projection in the Vicinity of Beach Nourishment Projects*. Prepared for Division of Beaches and Shores, Florida Department of Natural Resources, Florida Coastal and Oceanographic Engineering Department, University of Florida, Gainesville, Florida. 153 pp.

**DESCRIPTION:** The objective of this study was to develop and illustrate with examples of readily applied methods for predicting the 30-year time history of shoreline positions in the proximity of beach nourishment projects. As a response to State statutes regulating land use in designated coastal hazard areas, this was the first research to quantify the hazard mitigation benefits afforded by beach nourishment projects for obtainment of governmental accreditation. The authors outlined the role of profile equilibration, planform evolution (end losses), background erosion (historical erosion rates), shore-perpendicular retention structures, sediment size, wave height, and wave direction in predicting the performance of beach nourishment projects. Instructionary step-by-step procedures for both graphical and numerical predictive methods were created. Computational sheets for example problems were provided and numerous problems under various scenarios were worked out to illustrate the application of both predictive methods.

**RESULTS:** A mathematical equation was developed for long, unobstructed coasts showing that the time required to lose (through spreading losses) a certain percentage of sediment from a nourishment project area varies directly as the square of the project length and inversely as the 2.4 power of the wave height. Graphical and numerical analytical solutions were developed for predicting nourishment longevity downdrift of a littoral barrier using background erosion data (historical erosion rates) as a substitute for wave direction data. Four parameters (depth of closure, berm height, wave height and longshore diffusivity) were considered to be important in application of the Dean and Grant methodologies. Step-by-step procedures for calculating project length, sediment size, equilibrated project width, alongshore diffusivity, spreading losses, and historical erosion rates, provided 30-year predictions of shoreline positions (at 5- and 10-year increments) in the immediate project area and project adjacent areas for both uninterrupted shorelines and areas downdrift of littoral barriers.

**KEY WORDS:** Beach nourishment, Florida, 30-year setback, shoreline position, profile equilibration, sed-

iment transport, spreading losses, background erosion, retention structures, grain size, wave height, wave direction, alongshore diffusivity.

DIXON, K. and PILKEY, O.H., 1989. Beach Replenishment on the U.S. Coast of the Gulf of Mexico. American Society of Civil Engineers: *Proceedings of Coastal Zone '89 Conference*, New York, NY, pp. 2007-2020.

**DESCRIPTION:** The purpose of this study was to catalog the beach nourishment projects completed along the U.S. Gulf Coast and to determine the relative influence of the following parameters on fill longevity: fill length, volume, density, and grain size; proximity to structures; and storm frequency. Design and monitoring data for 35 beaches (100 pumpings) was compiled and interpreted. The predictive capabilities of the DEAN (1983 and 1988) models and the STAUBLE and HOEL (1986) model were evaluated based on the actual fill lifetimes as interpreted by the authors.

**RESULTS:** Many gaps and inconsistencies in monitoring data were found. Of 110 separate fill placements, 23 provided data suitable for comparing fill longevity, 7 (quantitatively) for grain size, 26 for cost and 43 for density. The authors interpretation of monitoring data "suggests that most U.S. Gulf Coast beaches experience durabilities of fewer than five years; 23% 'lasted' longer than 5 years; 54% 'lasted' 1-5 years, and 23% 'lasted' less than 5 years." Fill length was found to be the most influential parameter the longevity of fill placements. No influence was prescribed to fill density, fill grain size, and inlet proximity. The DEAN (1983 and 1988) models accurately predicted fill longevity for most Florida beaches but was an inaccurate forecaster for the remainder of the Gulf. The STAUBLE and HOEL (1986) model was classified as a poor predictor of longevity of nourished beaches on the Gulf Coast.

**KEY WORDS:** Beach nourishment, monitoring data, predictive models, fill length, grain size, fill density, groins, funding, emplacement timing.

FULFORD, E.T. and GROSSKOPF, W.G., 1989. Storm Protection Project Design-Ocean City Maryland, *Beach Preservation Technology '89*, American Shore & Beach Preservation Association. pp. 239-248.

**DESCRIPTION:** The authors described the integration of numerous interacting storm parameters and beach response numerical models for the design of an optimum cost-effective nourishment plan for Ocean City, Maryland. Wind, wave, and storm surge hindcasting models, as well as beach/dune erosion, wave setup, wave runup, and dune overtopping models provided output for six probability storms (5 yr., 10 yr., 20 yr.,

50 yr., 100 yr., and SPH). The Interactive Survey Reduction Program was used to evaluate alternatives for various volumes and beach widths, berm elevations, and dune widths and crests, along with a steel sheet pile bulkhead in restricted areas where dune construction was not feasible. The concepts of the equilibrium profile and closure depth were integrated into the scheme such that the volumetric requirements to obtain the design (after initial profile adjustment) beach width were estimated for the entire active profile. With the optimum plan in place, the estimated 100-year storm damages would be reduced by 85%.

**KEY WORDS:** Beach nourishment, Ocean City, Maryland, numerical models, equilibrium profile, closure depth, storm protection.

**KANA, T.W., 1989.** Erosion and Beach Restoration at Seabrook Island, South Carolina. *Shore and Beach*, 57, 3–18.

**DESCRIPTION:** KANA (1989) illustrated how the natural process of spit breaching during storms can be artificially mimicked on unstable tidal inlets and incorporated into innovative projects to nourish eroding shorelines. In February, 1983 Captain Sams inlet at Seabrook Island, SC was artificially breached across the updrift section of the ebb tidal delta and the natural inlet on the downdrift side was sealed. The optimum location and timing for the cut, (within political and financial constraints) was based on extensive historical analysis (1696–1979) of cyclic inlet dynamics, sand budgets, aerial photography, littoral process measurements, channel hydrography surveys, post- and pre-project profiling (to -5 ft), and wave refraction studies.

**RESULTS:** The primary change after inlet relocation was onshore movement of shoals from the abandoned tidal deltas. Although two years lapsed before mainland attachment, the shoals provided storm protection in the interim. From 1983 to 1989, there was a net gain of 2 million yd<sup>3</sup> and an increased beach width of more than 1,000 ft. Channel excavation and closure cost was \$300,000 and involved 175,000 yd<sup>3</sup>—a unit cost of \$0.50/yd<sup>3</sup>. The project produced expected environmental alterations, but many were beneficial and none resulted in long-term habitat degradation.

**KEY WORDS:** Shoal bypassing, beach nourishment, Seabrook Island, SC, wave refraction, ebb tidal delta, inlet relocation, environmental impacts.

**LANKFORD, T.E. and BACA, B.J., 1989.** Comparative Environmental Impacts of Various Forms of Beach Nourishment. American Society of Civil Engineers: *Proceedings of Coastal Zone '89 Conference*, New York, NY, pp. 2046–2059.

**DESCRIPTION:** The purpose of this paper was to review available environmental monitoring data and to demonstrate that the degree of biological impact along nourished beaches is largely influenced by nourishment methods. Existing projects were categorized by methodology: 1) offshore dredging; 2) inland trucking; 3) inshore dredging; 4) inlet stabilization; 5) inlet relocation; 6) intertidal beach scraping. Nourishment methods were evaluated based on project interaction with 10 criteria regarding habitat sensitivity and resource values: 1) incompatible sediments; 2) borrow and 3) nourished site fauna impact; 4) borrow and 5) nourished area species diversity/richness; 6) created habitat productivity; 7) borrow and 8) nourished area recovery time; and 9) borrow and 10) nourished area commercial/recreational value.

**RESULTS:** LANKFORD and BACA (1989) conclude (p. 2058) that “the majority of nourishment projects monitored to date along the southeastern U.S. coast have resulted in only minor, short-term adverse impacts.” Upland borrow sites and intertidal scraping were found to cause relatively insignificant impacts while offshore and inshore dredging and inlet relocation possess greater potential for lasting disturbance. Use of incompatible fill and damage to hard-bottom habitats from dredging have been causes of major biological impacts to date. Through proper implementation and use of numerous design alternatives it was argued that minimal impacts to biological resources in both the borrow and nourished areas can be achieved.

**KEY WORDS:** Beach nourishment, monitoring, hard-bottom habitats, Florida, South Carolina, borrow sites, biological communities.

**LARSON, M. and KRAUS, N.C., 1989.** Prediction of Beach Fill Response to Varying Waves and Water Level. American Society of Civil Engineers: *Proceedings of Coastal Zone '89 Conference*, New York, NY, pp. 607–621.

**DESCRIPTION:** An empirically-based numerical model of beach profile evolution was used to predict beach fill response to hypothetical storms and post-storm profile recovery. One hurricane and one extratropical storm with frequencies of 2–5 yrs. were imposed on two fill cross-sections, one with material placed above MSL in a steep-step berm and one with fill equally placed from +1 m to -2 m MSL (i.e., partial profile nourishment). Runs were made with compatible grain sizes (fill versus native) from 0.2 mm to 1.0 mm.

**RESULTS:** Regardless of initial fill cross-section, the model predicted pre-storm removal of fill from the inner surf zone and deposition over the profile beyond maximum placement depth (-2 m) (i.e., post-nourishment profile equilibration under typical wave conditions). Likewise, when subjected to both synthetic

hurricanes and northeasters, profile response was similar for both fill configurations. There was a strong decrease in eroded fill volume as grain size was increased through the range of 0.2 mm to 0.4 mm. For sizes larger than 0.4 mm volumetric losses were minimal and largely independent of grain size. Because of this, and because the cost of beach fill typically increases substantially for larger size material, the authors conclude that it may not be cost-effective to use fill with median grain size much greater than 0.4 mm (i.e., a declining B:C ratio for grains coarser than 0.4 mm).

**KEY WORDS:** Beach nourishment, numerical model, beach profiles, grain size, hurricane, northeaster, profile nourishment, berm nourishment, post-storm recovery.

**LEATHERMAN, S.P. and GAUNT, C.H., 1989.** National Assessment of Beach Nourishment Requirements Associated with Accelerated Sea Level Rise. American Society of Civil Engineers: *Proceedings of Coastal Zone '89 Conference*, New York, NY, pp. 1978-1993.

**DESCRIPTION:** This study represented the first estimation of sand volumes and costs required to nourish all existing and potential recreational oceanic beaches on a state-by-state basis in the U.S. for various sea level rise scenarios. Offshore borrow sites in 21 states were selected for analysis using ICONS surveys, supplemented with existing bathymetric data. Cost and volume estimates for six sea level rise scenarios from the year 2000 to 2100 ranging from 2.1 to 10.22 feet were analyzed.

**RESULTS:** The volume of sediment required to nourish and/or protect the nation's coasts by the year 2020 ranged from approximately 405 million to over one billion cu. yds. The associated cost ranged from \$2.3 to \$5.9 billion (1988 dollars). The quantities found in offshore borrow areas located to date would be capable of accommodating the nation's needs for only the two lowest scenarios over the long term.

**KEY WORDS:** Beach nourishment, sea level rise, volume, fill cost.

**ROELLIG, D.A., 1989.** Shoreline Response to Beach Nourishment. American Society of Civil Engineers: *Proceedings of Coastal Zone '89 Conference*, New York, NY, pp. 2104-2109.

**DESCRIPTION:** The performance of several nourishment projects authorized under Section 111 of the Rivers and Harbors Act of 1968 for Lake Michigan were described. Project monitoring over a 15-year period revealed invaluable information and resulted in modification of nourishment procedures which increased project effectiveness.

**RESULTS:** Monitoring revealed poor performance of fine sand nourishment and that serious consideration must be given to particle size for harbor mitigation projects. Gravel/cobble nourishment provided protection in the placement area about five times as long as fine sand. Gravel remained stable at the waters edge and continued to provide protection in down-drift areas whereas fine sand rapidly disappeared offshore.

**KEY WORDS:** Section 111, harbor mitigation, gravel nourishment, longshore transport, Lake Michigan, monitoring, grain size.

**ROELVINK, J.A., 1989.** Feasibility of Offshore Nourishment of the Dutch Sandy Coast. *International Conference Hydraulic and Environmental Modelling of Coastal, Estuarine, and River Waters*, Bradford, England.

**DESCRIPTION:** The purpose of the study was to compare the effectiveness of nourishing the upper shoreface through offshore placement versus direct nourishment of the beach. Using a vertically two-dimensional cross-shore morphological model, ROELVINK (1989) studied the effect of numerous offshore nourishment schemes on profile development between Hook of Holland and Den Helder. The author investigated the cross-shore dispersion of 100m<sup>3</sup>/m of nourishment material placed at offshore depths of 3, 5, 7, and 10 meters along three profiles over a period of six years.

**RESULTS:** For placement at 5 m depth, a considerable amount of the nourishment benefitted the higher part of the profile, resulting in a seaward shift in the upper portion of the profile. After approximately five years, the profile had stabilized and the maximum gain in the nearshore zone was reached. Comparison of 3, 5, 7, and 10 meter depth placements revealed that the relative gain of the profile increased with shallower placement depths. The time required to reach the maximum profile gain decreased with decreasing depth. For the Holland coast nourishment placement at depths greater than 8 m was found to be unproductive to the nearshore profile.

**KEY WORDS:** Offshore nourishment, nearshore profile, cross-shore profile, Holland, nourishment volume, placement depth.

**STRINE, M.A. and DALRYMPLE, R.A., 1989.** Beach Fill at Fenwick Island, Delaware. Center for Applied Coastal Research Department of Civil Engineering University of Delaware. *Report 89-01*. 61 pp.

**DESCRIPTION:** The purpose of this study was to determine the behavior and lifetime of beachfill placed at Fenwick Island, Delaware in 1988. STRINE and

DALRYMPLE developed a method for using historical erosion rates to predict beach nourishment performance and lifetime. Several beachfill projects completed on the East Coast were examined as well as a reexamination of data used by PILKEY (1988). Evidence was offered to refute PILKEY's (1988) pessimistic assessments of beach nourishment projects. The authors recommend that to objectively assess the performance of nourishment projects, the following should be developed: 1) definite limits of the beach profile being assessed; 2) criteria for defining "residence time"; 3) a standard and scientifically based definition of beach fill lifetime; and 4) provisions for avoiding assessments during the period of profile re-equilibration immediately after placement and especially extrapolation of loss rates based on this short-term assessment.

**RESULTS:** The authors found that the majority of beach nourishment projects on the East Coast that performed poorly were proximal to inlets or located in areas of known high historical erosion rates. To use historical erosion rates to predict beach nourishment performance, the authors cautioned that the following assumptions must be made: 1) that future erosion rates will be similar to historical rates (i.e., that wave climate will not change significantly); 2) that borrow and native sand is hydraulically equivalent; and 3) that future storm landfall in the project area will correspond to historical landfall frequency in the area. Although too little time had passed since completion of the Fenwick Island project to draw definite conclusions, the method of using historical erosion data to predict beach fill performance showed preliminary promise.

ANDERS, F.J. and HANSEN, M., 1990. Beach and Borrow Site Sediment Investigation for a Beach Nourishment at Ocean City, Maryland. U.S. Army Corps of Engineers, Waterways Experiment Station, Coastal Engineering Research Center, *Technical Report CERC-90-5*. 77 pp.

**DESCRIPTION:** This report discussed the methodology used in sampling and analyzing sediment from the native beach and borrow sites for the Ocean City, Maryland nourishment project. Several improvements in planning for data collection and analysis to improve borrow site evaluation were suggested. For each of 36 cross-shore profiles from the upper berm to -36 ft NGVD 11 core and grab samples were collected. Nine potential borrow sites were investigated during 1986-1987 through geophysical surveys and vibracoring (57 cores 20 ft in length) to determine site thickness, lateral extent and inclination. Composite grain sizes were calculated for the native profile and the borrow areas to determine overfill and renourishment ratios.

**RESULTS:** Sampling to a pre-determined depth (-36 ft) caused excessive sampling and incorrectly influenced the composite. The authors recommended that the chosen sampling closure depth be consistent with wave conditions anticipated during the span of a typical renourishment cycle, but in recognition of the occurrence of storms of lower frequency than the renourishment interval. Consideration of the small alongshore variability of sediment landward of the offshore bar would have reduced the required number of samples by half without sacrificing accuracy. A minimum of 1 core/1,300,000 ft<sup>3</sup> for potential borrow sites and 1 core/15,000,000 ft<sup>3</sup> for exploratory siting was recommended sampling density.

**KEY WORDS:** Beach nourishment, beach-fill design, borrow sites, closure depth, Ocean City, Maryland, overfill ratio, sampling, vibracores, linear shoals.

BRUUN, P., 1990. Beach Nourishment-Improved Economy Through Better Profiling and Backpassing from Offshore Sources. *Journal of Coastal Research*, 6, 265-277.

**DESCRIPTION:** Bruun advocated "profile nourishment" over "beach nourishment" and attributed the rapid loss of material from completed nourishment projects to the unnatural, "forced" steepness of the beach fill and the lack of consideration of the entire profile geometry. He predicted an increased utilization of profile nourishment in the future because of: 1) allowance for a wider range of grain sizes, 2) avoidance of rapid initial losses (reequilibration), and 3) lower construction and maintenance costs. Although profile nourishment requires a high degree of dredging equipment and diversification unavailable in the U.S., the author pointed out that adequate technology in Europe could be readily incorporated in the U.S. BRUUN also proposed "backpassing" of material to the shore at more frequent intervals (1-3 years) by installation of permanent offshore dredge and pump stations. Problems identified included limited (finite) borrow material and continuous disturbance of benthic communities and fish habitats. Technological modifications for overcoming damage to exposed equipment and maximizing economic efficiency of permanent stations were suggested.

**KEY WORDS:** Beach nourishment, profile nourishment, beach fill stability, nearshore profile, dredging technology, hopper dredge, backpassing.

CAMPBELL, T.J., DEAN, R.G., MEHTA, A.J. and WANG, H., 1990. Short Course on Principles and Applications of Beach Nourishment. Organized by Florida Shore and Beach Preservation Association and Coastal and Oceanographic Engineering Department, University of Florida.



**DESCRIPTION:** The purpose of this short course manual was to review the state of art and present the essential elements of beach nourishment design. The physical performance of beach nourishment projects were discussed in terms of equilibrium beach profiles and profile adjustment (cross-shore response) and sand transportation parallel to the coast (alongshore response). A basis for estimating beach nourishment needs and/or profile response under conditions of sea level rise was presented. The authors reviewed the sedimentological requirements for sand sources and the potential environmental constraints of beach nourishment. Guidelines and restrictions for the use of sediment from ebb tidal shoals in nourishment projects were outlined. The potential volumetric contributions from ebb tidal shoals along the Florida coast were inventoried. Under numerous variables and assumptions, the authors quantified the relationship between storm damage reduction and additional beach width gained by nourishment. Using the Indian River County, Florida nourishment project, the critical parameters and role of historical shoreline and volumetric change data in predicting the performance of beach nourishment and estimating the quantity and frequency of renourishment were outlined.

**RESULTS:** As a function of the beach profile factor and sediment diameter the model revealed that the coarser the nourishment material, the greater the dry (sub-aerial) beach width per unit volume placed. Based on the sediment grain size and unit volume, a generic classification scheme for nourished beach profiles was developed. Nourished profiles were defined as intersecting, non-intersecting, and submerged. An equilibrium beach profile model for nourishment projects was developed and applied to example projects and quantified results were presented. Under the BRUUN Rule (1962) where there is no onshore sediment transport during sea level rise, a design equation was developed to predict profile change and increased sediment needs in the future. Likewise, under the conditions of onshore sediment transport with sea level rise, an equation was developed for predicting profile response and/or sediment requirements. For a hypothetical nourishment project with a planform resembling a narrow perpendicular sand groin, it was found that the planform evolution evolves symmetrically about the perturbation even though the waves may arrive obliquely. For a more typical rectangular nourishment planform, models which predict "end losses" showed that the longevity of a project varies as the square of the project length. As was shown quantitatively for Bethune Beach, (Volusia County) Florida, end losses are indeed a very significant parameter for beach nourishment performance. In addition, wave height was found to be proportional to the  $5/2$  power in reshaping post-nourishment beach planforms that are initially out of equilibrium. It was mathematically shown that tapered-end planforms

have substantially greater longevity than rectangular planforms. The storm damage reduction benefits of a wider nourished beach were shown to be significant.

**KEY WORDS:** Beach Nourishment, longshore transport, cross-shore transport, storm damage reduction, end losses, equilibrium profile, historical erosion rates, ebb tidal delta.

**CHISHOLM, T.A., 1990. Hopper Dredge Direct Pumpout for Beach Placement. *Dredging Research*. DRP-90-2, 1-3.**

**DESCRIPTION:** The author described equipment and procedures which permit dredges with direct pump-out (DPO) equipment to pump ashore with emphasis on a single-point mooring (SPM) system. CHISHOLM (1990) focused on design and usage considerations and discussed the capabilities of dredging fleets in Europe and the U.S. While the European industry has effectively combined SPM systems with DPO hopper dredges, only two US companies currently put this technology to use.

**KEY WORDS:** Hooper dredge, direct pump-out, single-point mooring.

**DETTE, H.H., 1990. Offshore Sand Dredge and Delivery Systems. In: *Beaches: Lessons of Hurricane Hugo, Proceedings of the Third Annual National Beach Preservation Technology Conference*, L.S. Tait (ed.). St. Petersburg, Florida. pp. 378-393.**

**DESCRIPTION:** DETTE (1990) compared the advantages and disadvantages of two sediment delivery methods which utilized hopper dredges off the Island of Sylt/North Sea under operation conditions exposed to sudden high waves. To date, "trailing suction" with pressure activation has been favored. However, this method involves maximum penetration of 2-3 m and thus necessitates very large borrow (disturbed) areas and can prove environmentally unacceptable to authorities. Alternatively, DETTE (1990) described an anchored, stationary hopper dredging system, with penetration depths of up to 40 m below sea bottom. The "deep dredging" required relatively small borrow (disturbed) areas for an equivalent amount of sediment. The author suggested that deep dredging from anchored hoppers may prove to be environmentally more acceptable, although resedimentation rates of borrow areas requires further study. DETTE (1990) concluded that both methods are technically and economically feasible depending on environmental restrictions, sediment availability and location, and pumping distances.

**KEY WORDS:** Beach Nourishment, hopper dredges, stationary dredges, trailing suction dredging, borrow sites, environmental impacts, Sylt Island.

GALSTER, R.W. and SCHWARTZ, M.L., 1990. Ediz Hook—A Case History of Coastal Erosion and Rehabilitation. *Journal of Coastal Research*, Special Issue No. 6, pp. 103–113.

DESCRIPTION: In 1977–1978 a gravel/cobble beach nourishment/rock revetment project was constructed for \$5,600,000 on Ediz Hook in the Puget Sound, Washington State. Prior to project formulation, beach feed evaluation tests were conducted with placement of separate stockpiles of sand, gravel, and cobble. The project involved placement of 76,000 m<sup>3</sup> of gravel and cobble (2.5 to 30 cm) in five berm stockpiles of various sizes spaced at various locations. Monitoring included aerial photographs, hydrographic surveys, bottom sediment sampling, tracer studies, and side scan sonar surveys.

RESULTS: Some stockpiles failed to merge, leading to unprotected segments. In general, the authors state that “hydrographic surveys showed considerable restoration of the nearshore profile between LLLW and –3 m, seaward of which little change had taken place.” Seven years after project completion, only a 213 m segment of nourishment material remained exposed on the berm. Use of side scan sonar surveys proved effective, confirming considerable nourishment deposition in the nearshore and very little offshore movement, and revealing numerous submarine slope failures in very deep water at the distal end of the Hook. Evidence of slope failure of nourishment material suggested artificial recycling of material as a cost-effective maintenance method.

KEY WORDS: Beach nourishment, gravel, cobble, long-shore transport, monitoring, side scan sonar, recycling, stockpile placement, beach feed evaluation tests, Puget Sound.

HOUSTON, J.R., 1990. Discussion of: PILKEY, O.H., 1990. A Time to Look Back at Beach Replenishment (editorial), *Journal of Coastal Research*, 6, iii–vii. And, LEONARD, L.; CLAYTON, T., and PILKEY, O.H., 1990. An Analysis of Replenished Beach Design Parameters on U.S. East Coast Barrier Islands, *Journal of Coastal Research*, 6, 15–36. *Journal of Coastal Research*, 6, 1023–1035.

DESCRIPTION: The purpose of this discussion was to show that the analysis on which PILKEY (1990) based conclusions concerning beachfills was in error and cannot be used to draw meaningful conclusions about the performance of beach nourishment projects. Houston reinvestigated the pre- and post-erosion rates on 12 East Coast projects cited in LEONARD (1988) and LEONARD *et al.* (1990b). The source of the data used by LEONARD (1988) and LEONARD *et al.* (1990b) was retraced to original works and the

methods used by LEONARD (1988) and LEONARD ET AL (1990b) to adjust pre- and post-project erosion rates to a common base for comparative purposes was scrutinized.

RESULTS: HOUSTON maintained that the following errors in determining erosion rates were made by LEONARD (1988) and used by LEONARD *et al.* (1990b): 1) extrapolation from short-term measurements; 2) failure to consider the seasonality of erosion; 3) misinterpretation of original data; 4) reliance on unscientific data (e.g., press accounts); 5) failure to demonstrate how some rates were determined or to provide the original data on which they were based; and 6) post-fill measurements taken during initial profile reequilibration period. The author concluded that “all pre-and post-fill erosion rates given by LEONARD (1988), and used by LEONARD *et al.* (1990b) are wrong” and that the conclusions of LEONARD *et al.* (1990b) and PILKEY (1990) on the performance of beach nourishment projects were “extremely flawed.”

KEY WORDS: Beach nourishment, pre- and post-fill erosion rates, equilibrium profiles, beachfill performance.

KANA, T.W. and STEVENS, F.D., 1990. Beach and Dune Restoration Following Hugo. *Shore and Beach*, 58, 57–63.

DESCRIPTION: The authors describe five emergency beach nourishment projects along the South Carolina coast constructed after Hurricane Hugo. In all, 106,900 ft. of beach was nourished with 1,210,700 cy of sand at a cost of over \$7 million. Nourishment was principally executed with trucks, pan earthmovers, bulldozers and hydraulic hoes using inland pits, and accreted inlet shoals as source areas. The goal of the projects was to restore the beach profiles to pre-Hugo conditions or better. The authors describe the geotechnical, mechanical, bathymetric, economic and other requirements for formulating emergency nourishment plans, where fast-tracking is essential and funds are restricted. Federal requirements for funding emergency nourishment and federal/state/local cost-sharing arrangements are also discussed.

KEY WORDS: Beach nourishment, emergency nourishment, trucking, federal funding, state funding, maintenance agreements.

LEONARD, L.A., DIXON, K.L. and PILKEY, O.H., 1990a. A Comparison of Beach Replenishment on the U.S. Atlantic, Pacific, and Gulf Coasts. *Journal of Coastal Research*, Special Issue 6, pp. 127–140.

DESCRIPTION: This paper addressed beach nourishment projects on a national scale, comparing physical parameters and sociopolitical considerations of East.

Gulf, and Pacific Coast beach nourishment projects inventoried in PILKEY and CLAYTON (1988), LEONARD (1988), DIXON and PILKEY (1989) and CLAYTON (1989). Design parameters analyzed included fill length, density, and grain size. Storm activity and shore perpendicular structures were also evaluated. Three beaches determined by the authors to be representative of nourishment practices on each coast were compared. The Wrightsville Beach, NC; Captiva Island, Florida; and Carlsbad, CA schemes were all erosion control projects, with engineering designs, and continuous post-project monitoring.

**RESULTS:** LEONARD *et al.* (1990a) found that nationwide, beach nourishment projects are not routinely or systematically monitored. On all three coasts, the authors classified the longevity of the majority of fill projects between 1–5 years, with Pacific Coast projects generally lasting longer. The occurrence of storms and the presence of shore perpendicular structures were found to have the most influence on project longevity, while fill length, grain size, and density were found to have little or no discernable influence. The authors encouraged the nationwide adoption of Pacific Coast sand management practices (i.e., dredge spoil dumping on adjacent beaches) as opposed to East Coast practices of offshore disposal. The more frequent renourishment (maintenance) practices on the West Coast were recommended over single major pumpings and undependable maintenance commonly encountered on the East and Gulf Coast.

**KEY WORDS:** Beach nourishment, fill length, fill density, grain size, groins, sand management, bypass, storm activity, Wrightsville Beach, NC, Captiva Island, Florida, and Carlsbad, CA, project funding, background erosion, monitoring, maintenance.

LEONARD, L.A., CLAYTON, T. and PILKEY, O.H., 1990b. An Analysis of Replenished Beach Design Parameters on U.S. East Coast Barrier Islands. *Journal of Coastal Research*. Special Issue No. 6, pp. 15–36.

**DESCRIPTION:** The purpose of this study was to determine the “success” of beach nourishment, accuracy of predictions of fill retention time, and the effect of design parameters on 43 projects from New York to Florida. The authors defined “beach lifetime” as “the period between the time of initial emplacement of the sand and the earliest documented loss of at least 50% of the fill material.” The authors compared nourishment longevity predicted by the JAMES (1975), DEAN (1988), and STAUBLE and HOEL (1986) models to the observed renourishment requirements—i.e., 100% volumetric loss or when renourishment actually occurred. Parameters such as grain size, fill length, fill density, emplacement method, inlet proximity, groins, and storm frequency were compared to “beach lifetime” data.

**RESULTS:** Of 270 fill placements reviewed, 43 possessed monitoring data suitable for comparing fill retention, 35 for length, 32 for grain size and fill density, and 19 for storm history. Twelve percent of the projects were interpreted to have “beach lifetimes” of less than 5 years; 62%, 1–5 years, and 26%, less than one year. All predictive models inadequately measured the actual renourishment volumetric requirements and fill retention time when compared to the data collected by the authors. Nourished beaches were found to be much more unstable than native beaches. Fill length, grain size, and emplacement method (trucking versus pumping) were not important factors in post-emplacement fill response. Groins, fill density, and inlet proximity were found to exert influence on fill retention time. The most important factor influencing beach fill was found to be storm activity.

**KEY WORDS:** Beach nourishment, renourishment, maintenance, grain size, fill length, fill density, groins, inlets, monitoring, trucking.

PILKEY, O.H. and LEONARD, L.A., 1990. Reply to: HOUSTON, Discussion of PILKEY (1990) and LEONARD *et al.* (1990b). *Journal of Coastal Research*, 6, 1047–1057.

**DESCRIPTION:** The purpose of this discussion was to reply to HOUSTON's (1990) analysis which asserted that all estimates in LEONARD ET AL. (1990b) of pre- and post-fill erosion rates for 12 East Coast nourishment projects were wrong. PILKEY and LEONARD (1990) scrutinized HOUSTON's (1990) reevaluation on a case-by-case basis for 11 of the 12 projects in question. Evidence was offered in defense of their (LEONARD ET AL., 1990b) original erosion rates.

**RESULTS:** PILKEY and LEONARD found that HOUSTON (1990) was wrong in eight of his 11 reanalyzed cases. In only three of the projects were rates calculated by LEONARD ET AL. (1990b) found to be incorrect. The authors conclude that “our conclusions (LEONARD ET AL., 1990b) are valid.” The authors cite the following criticisms of HOUSTON (1990) analysis of their prior work: 1) incorrect assumptions of how rates were derived; 2) Failure to recognize critical conclusions in the literature; 3) use of data published after publication of LEONARD ET AL. (1990b); 4) criticism of an unpublished masters thesis (LEONARD, 1988) that was not the intended focus of the review. PILKEY and LEONARD (1990) lament the complexity and “softness” of pre- and post-project data as the major constraint to truly objective assessments, including their reviews and that of HOUSTON (1990). The authors concluded that until objective and high quality monitoring data are obtained, such exchanges (HOUSTON, 1990 v. PILKEY and LEONARD, 1990) will continue and little progress will be made on improving the performance of beach nourishment projects.