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The Development of Downdrift Erosion: an Update of Paper in JCR, Vol. 11(4)

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ABSTRACT

BRUUN, P., 2001. The development of downdrift erosion. An update of paper in JCR, Vol. 11(4). *Journal of Coastal Research,* 17(1), 82–89. West Palm Beach (Florida), ISSN 0749-0208.

Leeside-erosion is the terminology for the adverse effect on shore stability occurring on the downdrift side of a littoral drift barrier. Paper by BRUUN titled "The Development of Downdrift Erosion" published by the Journal of Coastal Research, vol. 14(4), 1995, explains that leeside erosion may have a short-range as well as a long-range effect, the latter being caused by the former. Between the two effects one may in some cases find an area of relatively less erosion making it protruding somewhat from the adjoining shorelines. In this paper more examples are given. It is concluded that the only fully reliable answer to the extent of the leeside erosion downdrift can only be obtained by qualitative research which will probably reveal that the leeside effect extends further downdrift than indicated by shoreline developments on the downdrift side.

ADDITIONAL INDEX WORDS: *Leeside erosion, littoral drift barrier, downdrift erosion, bypassing.*

INTRODUCTION

The 1995 paper was partly a result of the September 13–15, 1994 workshop, sponsored by the U.S. Army Corps of Engineers, WES, CERC, Vicksburg, with topic "Scoping Field and Laboratory Investigation on Coastal Inlets Research", held at Daytona Beach, Florida, and an earlier paper by BODGE (1995). The conclusion of the 1995 paper reads:

"The downdrift shoreline development at a littoral drift barrier may in some cases, but not always, be described by a short (local) as well as a long distance effect which both move downdrift at various rates; the long distance movement being 2–3 times faster than the short distance, or about ~0.5km/year versus ~1–1.5km/year. These figures may be subject to considerable variances depending upon wave intensities, barrier morphologies and littoral drift magnitudes as well as upon the relative predominance of the drift. The short distance effect is a coastal geomorphological feature, the long distance a materials deficit feature.

To clarify all details of littoral barrier effects with respect to the fate of materials which were pushed seaward by the barrier would require comprehensive tracer and/or beach drifter tests, the results of which would be highly weather dependent. Also the conclusions of such tests would be mainly qualitative. However, they would give information on the gradual fading out of the leeside effect along the downdrift shore, still realizing that some material may be lost to deeper sections of the bottom profile and thereby be lost to the beaches downdrift causing erosion."

Followed by some remarks on the need for bypassing and public agencies shortcomings in realizing the problem in some countries. While the 1995 paper has been well received and accepted by its examples, it has also given rise to some discussion and supplementary views as *e.g.* the "bump" could be a result of a rock or other solid outcropping in the nearshore waters. This proved to be true for the St. Lucie Inlet case. The bump, however, could also indicate the place, where material pushed out by the littoral drift barrier would tend to return to shore. This may sometimes be observed, *e.g.* when an inner bar moves in close to and finally attaches itself to the beach (Figure 1). The most common cause could be a result of a reversal of the littoral drift downdrift of the barrier as explained in the 1995 paper with reference to Figure 8 in the paper. But the bar or shoal does not always return to shore. At tidal entrances on littoral drift shores, the ebb shoal retains material. Quite often even more material is captured in a larger shoal downdrift, as it *e.g.* happened at the South Lake Worth Inlet, Figure 2. Such shoal or bar may hold quantities of material counted in millions of m^3 without releasing it or only releasing a part of it further downdrift. The shoal in itself may function as a submerged breakwater for the shore inside which in turn may cause a twist between those having properties on that shore and those who want the shoal "shaved" by transferring material downdrift to eroding beaches. Approximately $420 \times 10^6 m^3$ sand is captured by the inlet's ebb shoals on the Florida coast.

SHIRASHI *et al.* (1978) mention the development of the shoreline downdrift of the Port of Oarai breakwater in Japan. This problem was investigated by field observations and by hydraulic model experiments by which the littoral currents were measured in 17 points as indicated in Figure 3. Wave heights were 0.5 to 0.8m, periods 10–12 sec by waves from the Northeast. The authors claim full similarity between the field and their model using sawdust and coal powder as sediment in the model. Figure 3 shows the current modes and velocities recorded in the field. The results tend to confirm

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Figure 1. The northern part of Sandy Hook, New Jersey, demonstrating groin—effect and attachment of bar to shore (ALLEN and NORDSTROM, 1977).

the leeside shoreline development shown in the authors Figure 8 (1995), which demonstrates a "bump" in the shoreline and split-current modes on either side of the bump.

MONTOYA, VERA and SOTO (1994) investigated the shoreline development downdrift of the west breakwater at Puerto Madera, built 1972, on the southern part of Mexico's Pacific. Figure 4 shows the development between 1973 and up to 1978. During that period 17 groins were built during 1975–1977 and 2,850 meters of seawall was constructed 1978–1990 from the breakwater to groin no. 17 (Figure 4). The shoreline development is best illustrated by the shorelines of October 1975 and May 1978 (upper figure) and includes a bump with eroding features on either side. The same is true for the development 1978–1985 (lower figure), *e.g.* by the shoreline December 1984, March 1985 and 1991 configurations. The groin field and the sea wall may have obscured the development somewhat and migration rates are impossible to determine.

Paper by NERSESIAN *et al.* (1992) mentions the functioning of an extended field of 15 long rock groins construction at

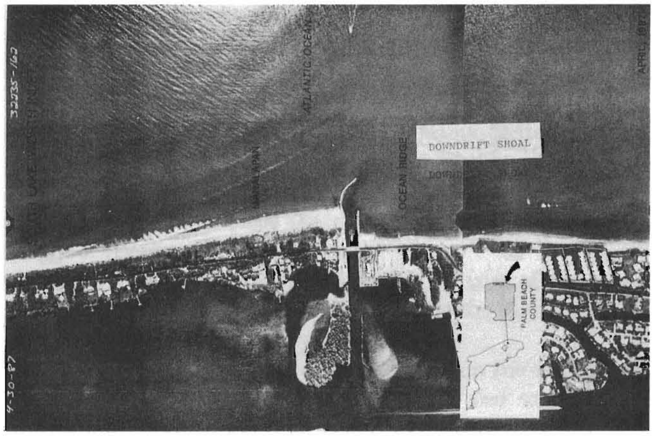


Figure 2. South Lake Worth Inlet, Florida. Observe downdrift shoal.

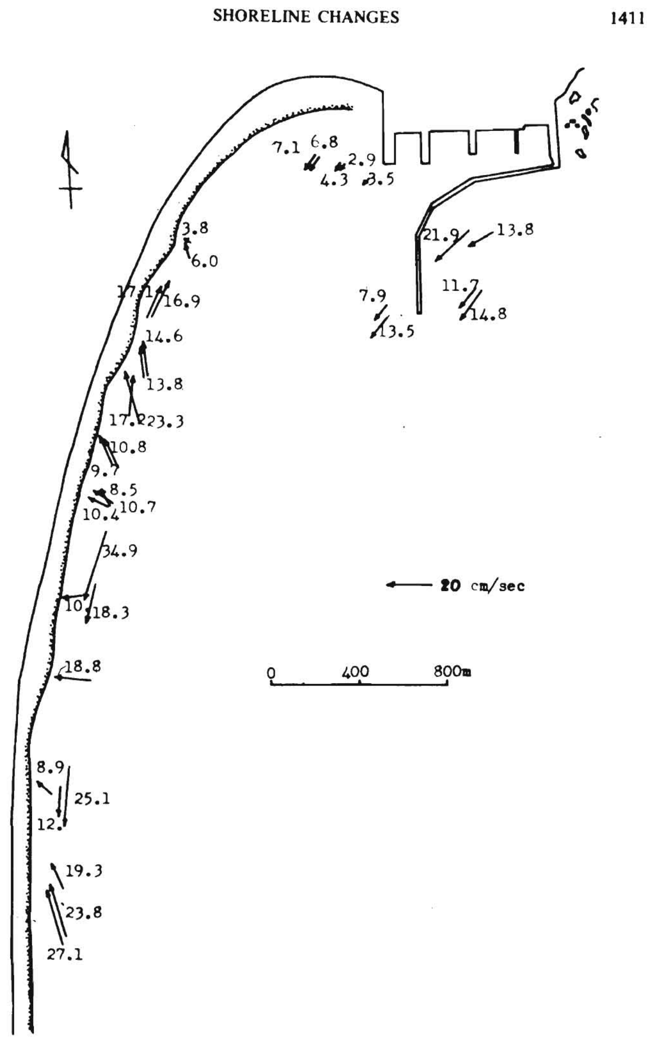


Figure 3. Littoral Currents along the Orai Coast (SHIRAISHI *et al.*, 1978).

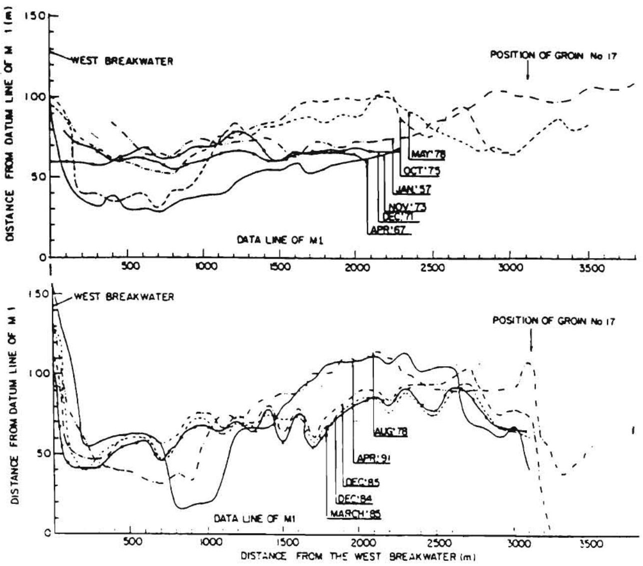


Figure 4. Shoreline Change west (downdrift) of the Puerto Madera breakwaters, Mexico Pacific (MONTOYA *et al.*, 1994).

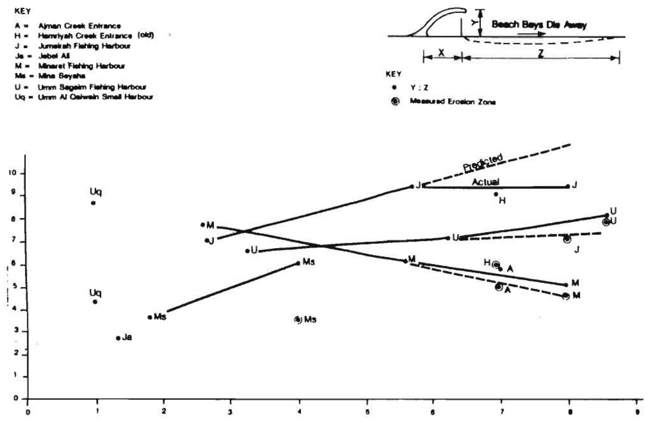


Figure 6. Seaward Extensions vs. Downdrift Influence of Harbours, United Arab Emirates (MADDRELL, 1990).

Westhampton Beach, Long Island, in increments with 11 groins in 1965–1966 and 4 groins in 1969–1970. The paper explains how accretion took place inside the group and how leeside erosion developed downdrift 1975–1991. In cit. referring to Figure 5:

"In the shore area encompassed by the second group of 4 groins, shoreline advance over the period 1966–89 was 50–55m, or about 2.3m/year, and was probably influenced in part by the dune and beach fill that was artificially placed during the second increment of work. In the period 1975–89, there was a shoreline advance of 40 to 20m or 2.9 to 1.4m/year, respectively, from east to west, in this area. At a point about 370m west (downdrift) of Groin 15, the shoreline receded about 6.5m/year in the period 1975–89. Further westward the rate of recession decreased to about 5.0m/year. It is noted that the shoreline recession between 1962–75 was 1.9m/year or less. Accordingly, the rate of recession in the downdrift area tripled following completion of the second increment of work."

The paper does not analyze the leeside development in detail, but Figure 5 clearly shows it *e.g.* by the 1979 and 1989 shorelines. Both reveal the "up and down" development downdrift until further development apparently was influenced by the Moriches Inlets updrift that is towards the west in Figure 5. MADDRELL (1990) investigated the influence of port breakwaters downdrift for a littoral drift coast in the Arab Emirates (Oman) on the Persian Gulf. Figure 6 shows results giving the Y/Z ratio (see figure) in relation to the years since completion of the breakwater barrier for littoral drift which is of the order of 100,000 m³/year going Northeastward. The most general trend is that during the final 2–5 years the Y/Z ratio levels were ~7–9 with decreasing tendency for the smaller ports and ~3 for the major ports for a

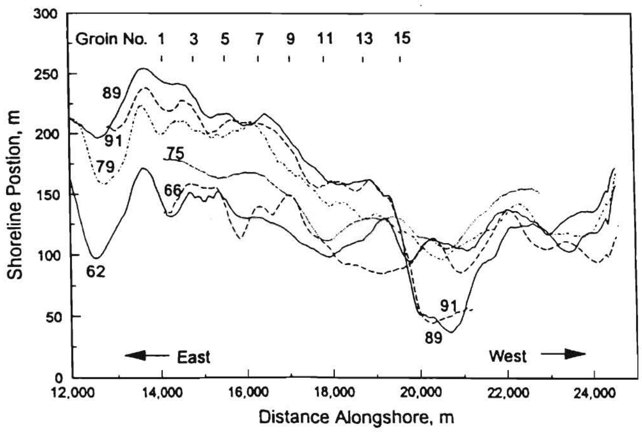


Figure 5. Smoothed Shoreline Position in the Vicinity of the Groin Field, Westhampton Beach, Long Island, New York (NERSESIAN *et al.*, 1992).

Figure 7. The Soft Harbor Marina, Lake Erie, leeside erosion (RAYMOND and TAYLOR, J. Coastal Res. Special Issue No. 26, 1998, pp.).

Figure 8. View of the growing delta at the mouth of the Itanhem River, Brazil. Ebb flow with muddy water. Shoals are indicated by a breaker line, 600m east of the extremity of the spit. Heavy downdrift erosion. (DUPONT, 1998, J. Coastal Res., Special No. 26, pp.).

short period of time. No information on migration rates was obtained but is seems to be smaller or 0.1–0.2km/year.

Figure 7 (RAYMOND and TAYLOR, 1981) is an aerial view of Soft Harbor Marina in Lake Erie looking toward west. Leeside erosion is very severe. On the east side of the harbor, LEO-data indicate that the harbor causes typical southwest-northeast wave trains to bend and hit the coast more abruptly, causing currents that would more likely remove sand to deep water rather than to move it along the beaches, as occurs on the west side. For sediment to survive long on these beaches it would therefore most likely have to be even coarser than the average sand to gravel of the western beach and nearshore zone.

Figure 8 (DUPONT, 1998) from the Bahia State in Brazil, shows how a tidal inlet by its huge ebb shoals established a littoral drift barrier of great magnitude causing severe beach erosion on either side of the shoal of great concern for the Town of Alesbaca, a seaside resort.

Figure 9 (GULER *et al.,* 1998) gives the result of a seasonal simulation of an entrance stabilization for the Managuat River on the Turkish Mediterranean.

It may be noted that the drift coming from the right (west) caused accumulation on the updrift side and scour on the immediate downdrift side with a large "bulge" to follow. This corresponds to the result given in Table 1 of BRUUN (1996).

Figure 10 (KOMAR, 1983) shows shoreline changes at the Port of Madras in India, 1876 representing the pre-breakwater shoreline. Rip rap placement immediately downdrift of the harbor limited the extent of the erosion but leeside erosion has continued downdrift until the next port installation. Said new port has by itself caused further migration of the leeside erosion—a "chain process".

Figure 11 shows the shore at the Town of Quarteria in Algarve, Portugal. The development of erosion of this shore is described by PEREIRA *et al.,* 1998. The harbor at Quarteria undoubtedly has a great deal of responsibility for the development of erosion east of the harbor. During the period 1971–1973 two harbor jetties were constructed with lengths 500m

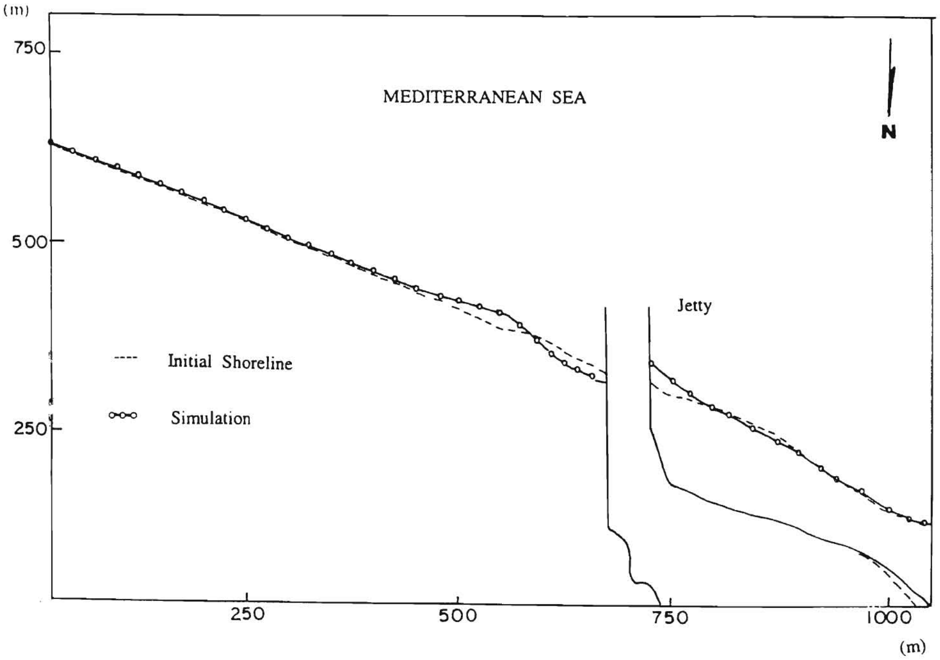


Figure 9. Turkish Mediterranean. Stabilization works at the Managuat River entrance. Initial shoreline (dotted line), Simulation shoreline O-line. Leeside erosion with bulge downdrift (GULER, EYSEN and YALCINER, J. Coastal Res., Special No. 26, pp.).

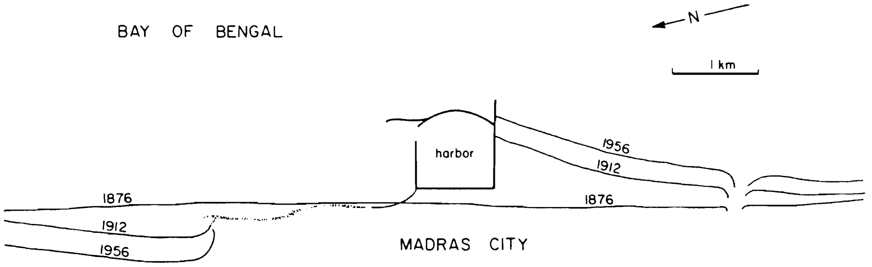


Figure 10. Shoreline change at the Port of Madras on the SE India shore. Leeside erosion limited by placement of rip Rap followed by further extension of the erosion, most recently influenced by a new harbor further Downdrift extending leeside erosion even further (KOMAR, 1983, pp.).

and 600m respectively. Realizing the problem which would arise twelve 140 m long groins were built east of the harbor as seen in Figure 11. The combined littoral drift barrier caused an increase of the erosion of the beach and the sand cliffs east of the groined shore. The 1995/1996 survey showed that the average retreat at Forte Novo was approximately 5m/year. In the adjacent sector of Trafal it was only 1.9 m/year, followed by successively higher values for Central Vale do Lobo and Vale do Lobo East, 2.49 m/year and 3.29 m/year respectively.

Figure 12 gives a graphical presentation of this development. Eroded volumes apparently show the same trend as shoreline recessions.

Although seasonal fluctuations may have caused local variances it seems obvious from Figure 12 that the development of leeside erosion followed similar patterns as explained by BRUUN, 1995 comprising a heavy shoreline retreat immediately downdrift of the barrier, next a "bulge" with relatively little erosion followed by an increasing shoreline retreat after the bulge. The migration rate of shoreline reaction to the barrier has been of the order of 300 m/year, which corresponds to the earlier results (BRUUN, 1995).

A paper by ROSATI and EBERSOLE (1996) examines the Ocean City Inlet, Maryland, in considerable detail, as it is a data-rich site for evaluating the total littoral impact of a inlet system with a significant adjacent beach response next applying the even/odd method which decomposes shoreline changes in their symmetric (even) and antisymmetric (odd) components about a "point of significance" in conjunction with beach and bay shoreline data, beach profiles, ebb and flood shoal evolution and dredge and fill history, thereby providing a quantitative database for the inlets littoral impact to adjacent beaches. Figure 13 is Figure 2 of their paper and shows clearly the influence of the inlet at ±15 kilometers from the center of entrance. The inlet-sink analyses, assuming pre-inlet trends continued through the present, indicated,

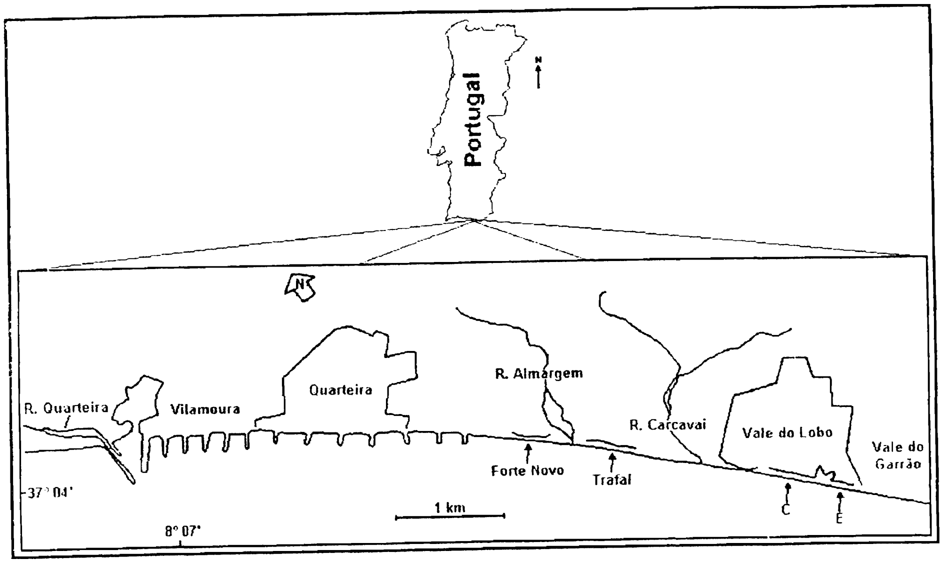


Figure 11. Location of the study area at the coastal town of Quarterira (Algarve, Portugal). (PEREIRA, H.; GUERREIRO, V.; DIAS, J.M.A., and FERREIRA, O., LITTORAL 98, Barcelona, Spain).

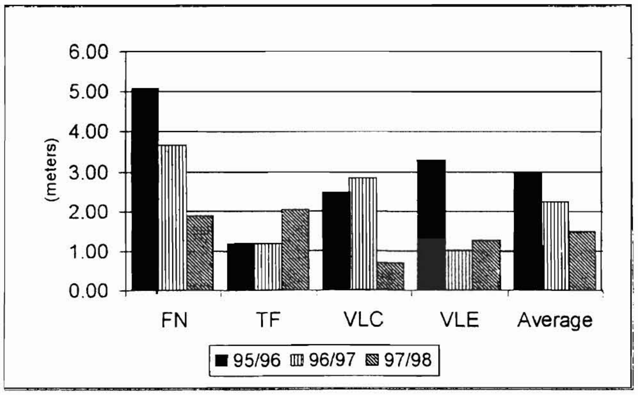
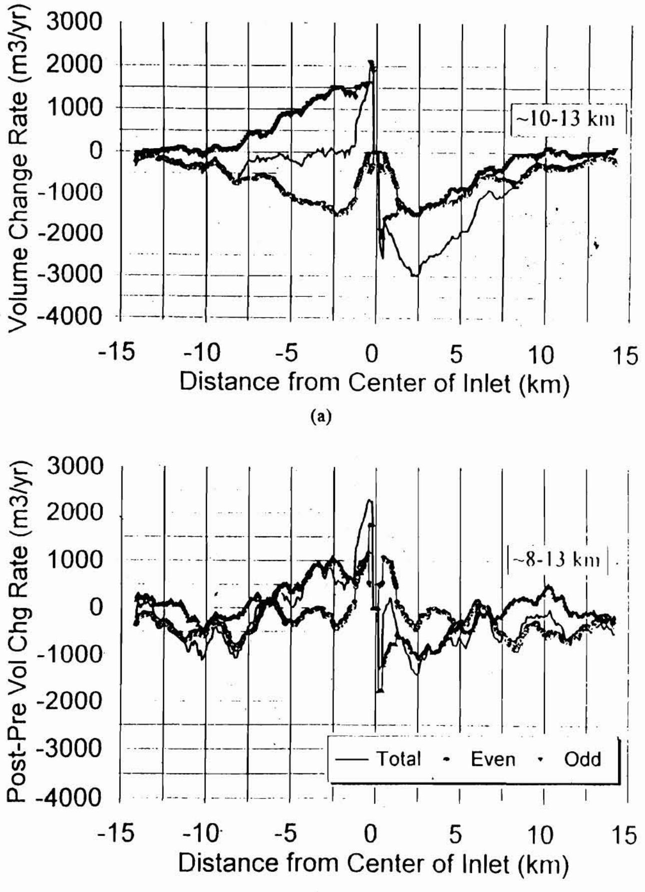


Figure 12. Shoreline Retreat in Forte Novo (FN), Trafal (TF), Central Vale do Lobo (VLC), Vale do Lobo East (VLE) and the total average, for the last three winter seasons (PEREIRA, H.; GUERREIRO, V.; DIAS, J.M.A., and FERREIRA, O., LITTORAL 98, Barcelona, Spain).



(a)

(b)

Figure 13. Total volumetric change, even and odd functions for (a) post-inlet volume change rates (1929/33–1996), and (b) post-inlet minus pre-inlet (1850–1929/33) volume change rates (ROSATI and EBERSOLE, 1996).

at most that 10.8 million m^3 can be realized along 14.2 km up and downdrift ocean and bay shorelines. This analyses therefore revealed that the alongshore impact distance most likely exceeds the available data limit (±14km from the centerline of the inlet).

More detailed information provided by ROSATI (pers. communication) indicated the presence of a "bump", for 1980–1996, compared to about the same value on either side of the bump, moving shoreward. Due to the length of the wave-like bump, which is 1,000m it can hardly be interpreted as a migrating wave in the shoreline. Its geometry does not fit such a wave.

QUANTIFICATION OF LEESIDE EROSION

Quantification of the leeside erosion may be approached from two angles:

(1) Investigation on how far downdrift the shoreline evolution is affected by littoral drift barrier.

This approach used in the above mentioned examples. The influence extends as far as an increase of the normal shoreline recession can be noted. When shoreline-recession starts picking up downdrift this, of course, may have more than one reason which *e.g.* could also be the result of extreme storms or it could be caused by an unforeseen development of the offshore bottom—or perhaps ultimately by a rapid increase in sea level rise. It is important to evaluate the shoreline recession as it is when unaffected by the drift barrier. The even-odd method (ROSATI and EBERSOLE, 1996) is one way of circumventing the problem.

A practical checking may be possible by a quantification approach, which must include sensitivity-analyses.

(2) Evaluation by quantification means that the influence by the barrier on the drift has to be accomplished by quantifying the interruption of the normal drift. This depends upon our ability in determining drift quantities as function of wave and current climates. On the straight shore such evaluation may be investigated by various drift formulas but their reliability usually is questionable because of the lack of proper field data. See *e.g.* WANG *et al.,* 1998. A more reliable and practical way of determining the drift is by observation of quantities of materials deposited at the littoral drift barrier(s) by accumulation on the updrift, offshore and downdrift shoals caused by the barrier and by deposits within the barrier itself, *e.g.* in the navigation channel and/or in traps. Paper by MEDINA *et al.* (1998) titled "Application of a long term evolution model on Tidal inlets to the Design of a Navigation Channel, the Napia Inlet", probably describes one of the most practical methods at this time. Gathering of information from a great variety of sources including inputs of field data will gradually build up a file of information useful for practical comparisons. At the same time the erosion downdrift may be followed by frequent profile surveys at intervals which are spaced to provide a reliable calculation of the quantities which may have been lost or gained. Such procedure is followed as far downdrift as possible to determine the development of erosion or ac-

cretion along the shore. Ultimately these calculations will refer to the "natural condition", unaffected by the barrier. ROSATI and EBERSOLE (1996) describes such occurrence when calculations of quantities finally revealed that the adverse effect of the Ocean City Inlet in Delaware must extend farther away from the inlet than indicated by just changes of shoreline-configurations.

The above mentioned approach, of course, is highly dependent upon the depth of the profile up to which calculations are extended. In this respect one probably has to distinguish between "short time range" and "long time range". The former should not be too short, so that results may be masked by a number of short term variances. "Short term" could *e.g.* be 5–10 years and extend to the 10 year limit for "active movement of bottom material" (BIRKEMEYER, 1995). "Long-term" could involve time-intervals of 30–40 years. It would also extend farther downdrift and offshore to the active depth of movement under *e.g.* 30–40 years period. While sea level rise may be disregarded for the short-term it should be included for the long-term. Regarding the barrier itself one has to consider the loss of material to the offshore *e.g.* due to inlet ebb-currents and similarly for the loss to bay bottom areas of fine materials visible in clouds on aerial photos. The evaluation may be done by combining ebb and flood flow discharges with sediment concentrations secured by sampling or aerial photos combined. The "exact" quantities will anyhow be subject to variances which may be determined by "sensitivity-analyses". For proper corrective steps questions could be:

(a) What kind of quantities, by order of magnitude, are we facing and how much do they vary
(b) For corrective steps, how are the needs for bypassing distributed considering first shoaling of the navigation channel
(c) Next consider shoaling of offshore and bay shoals
(d) Third, how critical is the downdrift erosion. Is it necessary to launch a major nourishment operation replacing *e.g.* material lost during the latest 10 years or will initiation of intermittent transfers at certain time-intervals suffice. Finally, shall a permanent bypassing arrangement fixed or movable, be established for continuous bypassing, possibly preceded by a major "shot in the arm" on the downdrift side by materials from offshore.

These are technical problems which can be solved by technical means. Financing is usually the real problem which can be solved by negotiations between parties involved. In this respect the Florida laws of 1985/86 are probably the most advanced in the world by their clear statements of obligations to undertake bypassing in full at littoral drift barriers (in Florida tidal entrances) or replacement of material lost under all circumstances, with other materials, which means nourishment from offshore sources. Such "radical action" seems to be well justified based on considerations to:

Property rights, which were violated
Coastal ethics, which were violated
Environmental aspects, including aesthetics

Property rights are usually guaranteed in a constitution as a basic demand with perhaps some obvious exemptions.

Coastal ethics may be expressed as "thou shalt not steel thine neighbors property" (BRUUN, 1972)—or, if you erect a structure on your property which will have or has a damaging effect on the property belonging to others you are liable for the damages such structure inflicts upon such neighboring property and must bear the consequences.

Damage to the environment by a coastal structure is always very visible, because erosion leaving an "open wound" in the shore looks ugly. Such damage may also spread to inshore areas *e.g.* in the form of sand drift by wind which may cover vegetated areas with barren sand and live dunes. Another adverse effect is that the water table in inland areas is lowered with damaging effects on the ecology. A third damaging effect is the influence on aesthetics. An eroding shore does not offer a pleasing view. Only a few extremists will claim that a damaged nature, whether the damage is a result of erosion, floodings, earthquakes or volcanic eruptions, offer a "natural view". We have to live with nature's bad habits of inflicting damage on nature, but man-induced damages are always uncomfortable, because they appear as an illness inflicted upon the natural environment.

The problem which has arisen due to man-inflicted damages is that the damage was permitted to occur although in most cases it could be and also was foreseen. This happened without defining the responsibility, and place it where it belongs. Many countries are still suffering from that kind of shortcomings in their administration. The Florida inlet law is very clear in this respect, but—at this time—some responsible agencies who permitted this to happen are reluctant to admit their responsibility. They do not consider their responsibility in the coastal ethics system. It is of course not right, if this shall be allowed to continue. And it is unfortunate that administrators too often are short of education in the physical sciences and handle problems as "cases" (2×2 may be 7) instead of as "matters" ($2 \times 2 = 4$).

HOW IS THE FUTURE GOING TO DEVELOP

Let's look at the situation in Florida. The inlet bypassing law was passed in 1986/87. Progress has come slowly. It was an adjustment to get acquainted with the law and its goals. To activate the law fundings were needed. First data, as reliable as possible, had to be secured. Recent years have brought an increase in studies supported by state funds which has been fortunate. The step to follow is actions which are well prepared. So far only one tidal entrance in Florida, the Hillsboro Inlet north of Miami, has lived up to just about full bypassing, but more will follow. An improvement of technologies for bypassing, however, is essential. The old fixed type updrift pumping plants have proven to the ineffective. The Palm Beach Inlet is just one example. A higher degree of flexibility and considerable improvements of capacities is necessary. As explained by VISSER and BRUUN (1997) this is possible partly by floating plants like the Shallow Water Hopper Dredger and partly by the installation of submerged pumps in the bottom of the navigation channel possibly including fluidization pipes placed to fluidize materials to be flushed away by currents or slurries to be carried to the pit of the submerged pump for transfer to downdrift beaches. At this time tests have been run which seem to justify such installation (BRUUN, 1990, 1996 and 1997).

The necessity of combining beaches and dunes as an adamant criteria for an effective coastal protection is being fully realized (BRUUN, 1998).

CONCLUSION

Not enough new material has become available to change the conclusions drawn in the 1995 paper regarding migration rates of leeside erosion. The long range erosion trend is a fact observed by many. The bump is well known and is probably most likely to occur, where the predominant direction of the littoral drift is most pronounced. If material is placed in or transferred to the short-range zone this, of course, will be beneficial also to the long-range zone.

What we need, of course, is more quantitative data formulated in reliable material budgets as also attempted by some researches like ROSATI and EBERSOLE (1995) and also by MADDRELL (1990). Inlet management studies are helpful in this respect. But it is often difficult to distinguish "natural erosion" from the erosion forced upon the shore by the littoral drift barrier. Better and more accurate survey techniques, however, will be helpful in establishing a more reliable database. Tracing would also be an advantage, but it is very time-consuming and expensive.

Results of research on quantitative determination of leeside erosion and its migration downdrift, however, are expected to become available in a near future. They will still be dependent upon variances due to complexities associated with physical factor variances.

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