Evaluation of the Effect of 20 Years of Nourishment

Christian Laustrup[1] and Holger Toxvig Madsen[2]

Abstract

Since 1982, large-scale coastal protection works have taken place on the Danish North Sea coast. The subject of the first part of this paper is the coastal protection policy, the engineering approaches to erosion and flood control and the results achieved. An important tool for coastal protection has always been and still is nourishment. In the second part of the paper, thc effect of the nourishment will be evaluated with focus on the positioning of the nourishment in the profile and on the use of coarse materials.

1. Introduction

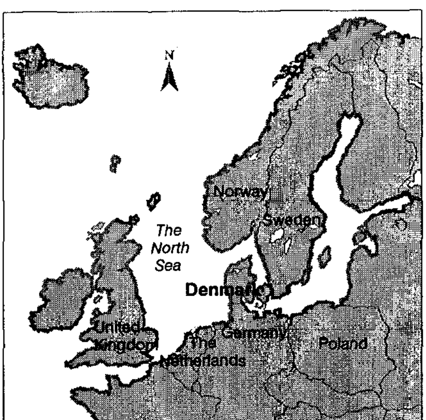

Figure 1. The North Sea countries

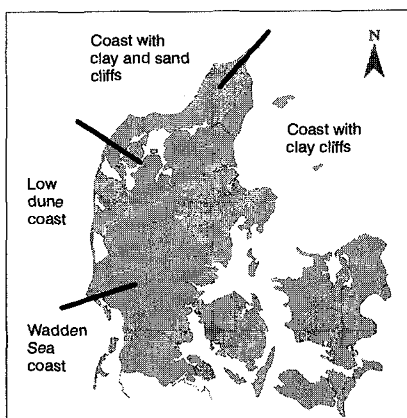

Figure 2. Classification of the Danish coasts

The Danish coastline is 7000 km long. Roughly speaking, there are four different types of coast:

1 Deputy Director
2 Senior Coastal Engineer
Danish Coastal Authority, Box 100, DK7620 Lemvig, Denmark, E-mail: ki@kyst.dk

- A tidal coast with a tidal range of 1.5 - 2 m where the low hinterland is protected against flooding by dikes.
- The southern part of the North Sea coast with sandy beaches where dunes protect the low hinterland against flooding.
- The northern part of the North Sea coast with sand and clay cliffs.
- The Baltic Sea coasts mainly with clay cliffs.

Figure 3 illustrates the different degrees of exposure.

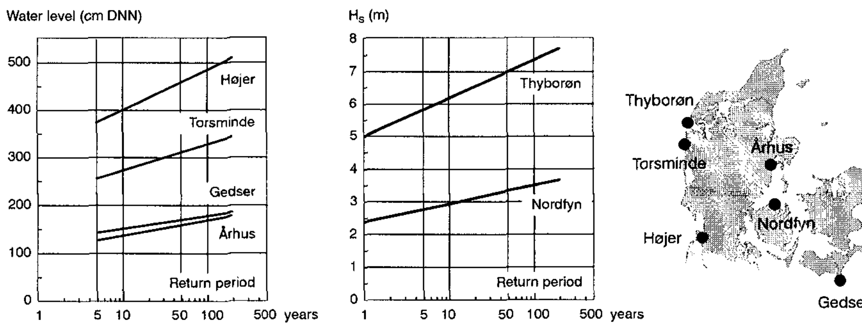

Figure 3. Water level and wave height statistics

2. The coastal protection policy

2.1 Regulations and funding

In Denmark, we do not have a basic coastline defined by law as it is the case in for example the Netherlands. For the two major dikes in the tidal region, the dike safety level was decided by the government to be a 200-year return period. Apart from that, there are no national rules for safety assessment of dikes or dunes. The actual policy for safety assessment and the erosion control policy are established as an agreement between local authorities and the government based on Danish Coastal Authority recommendations. There are probably a number of reasons for the lack of national regulations but the main reason is that apart from the land protected by the two main dikes, the danger to human life is small and "only" land is damaged by erosion and flooding.

The costs of coastal protection on the North Sea coast are shared between the government and the local authorities. The government typically pays 50 to 70 %. In some cases the government pays 100 %.

On the Baltic Sea coasts, coastal protection is regulated by an act passed in 1988. According to this act, the counties are responsible for the administration of coastal protection projects. Since the counties do not have any coastal engineering expertise, the Coastal Authority provides assistance at the planning stage and the consultants provide assistance at the project stage. The general practise is that there is no public funding of coastal protection in the Baltic Sea area. Here the individual landowner has to bear all the costs.

2.2 The situation and strategy in 1982

The following chapters deal with the problems on the North Sea coast, especially on the southern part of the coast.

Figure 4 shows the coastline retreat rate before 1977 for the southern part of the North Sea coast. There are very high rates of leeside erosion caused by harbour breakwaters and large groyne groups. Besides the loss of valuable recreational areas, the high erosion rates had the effect of significantly reducing the protection against flooding provided by the dunes.

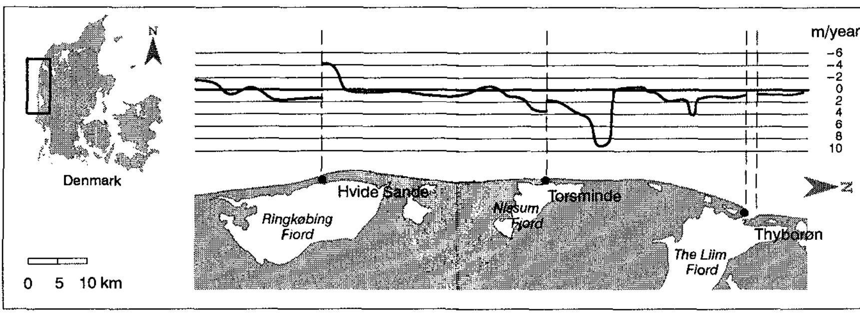

Figure 4. Retreat rates before 1977

About 100 years ago, the dunes were stabilized by marram grass planting. At the same time, harbours and groyne groups were built which resulted in serious downdrift erosion. The combined result of the stabilization of the dunes and the erosion was that in 1982, the dunes had disappeared or were weak along 50 km of the coast. So in 1982, it was decided to implement a coastal protection scheme.

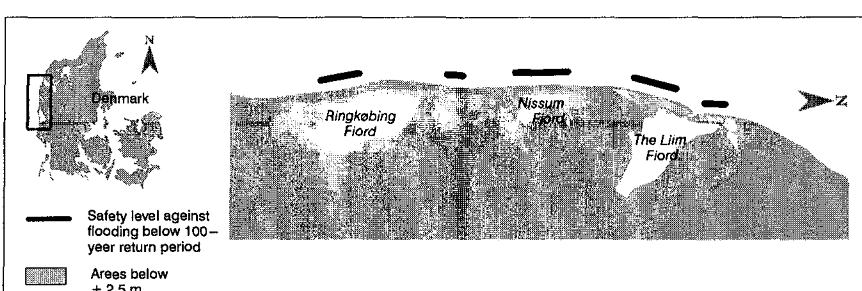

Figure 5. Low areas and critical safety levels

The headlines of this policy were:

- To re-establish a safety level against flooding to a 100-year return period minimum.
- To stop the erosion where towns were situated close to the beach.
- To reduce erosion on parts of the coast where erosion in the near future would reduce the safety against flooding to less than 100 years.

The dunes were reinforced and new dunes were built to re-establish the safety against flooding to a 100-year return period. However, in many cases it was not possible to reach the safety level required because there was not enough land between the beach and the houses or the road to build a sufficient dune volume. In this case, the dunes were protected by a revetment.

Placed concrete block revetment

To stop or slow down the general erosion of the coastal profile, the following approach was used:

- On highly exposed stretches where erosion should be stopped, low detached breakwaters were used in combination with nourishment. One reason for the use of breakwaters was that for historical reasons, local politicians trusted in hard structures like groynes and breakwaters. Another reason was the high price of the nourishment sand.
- Nourishment was applied but on a small scale. The main reason for this was that the principle of beach nourishment was new to the politicians. It was difficult to convince the politicians that "the erosion of the nourishment sand during storms is part of the plan". This meant that volumes were small and unit costs were high which was one reason for stabilizing the nourishment by means of breakwaters.

Detached breakwaters, beach nourishment and revetment

Rubble-mound breakwater

2.3 Important developments since 1982

Figure 6 shows the coastline retreat rate in 1998 for the southern part of the North Sea coast. The very high erosion rates are no longer a fact. We do not have an absolute zero erosion but the erosion has been stopped where it is important for the dune safety and on average, the coastal erosion rate is 0.1 m/year.

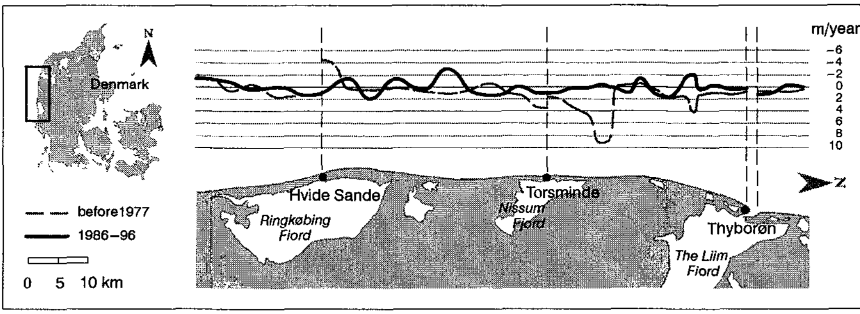

Figure 6. Retreat rates 1986 - 96

The safety level of the dunes has been re-established to a level of at least 100 years which was the goal in 1982.

Figure 7 shows the development in the use of structures and beach nourishment for the period, including costs.

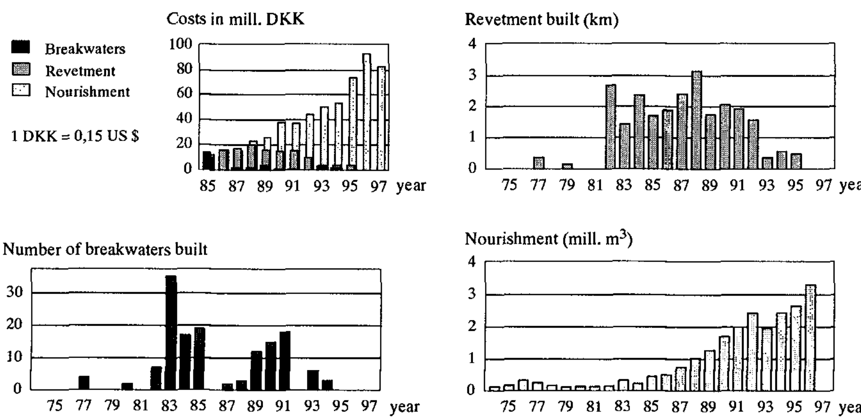

Figure 7. Development in the use of structures and nourishment

The effect of using low detached breakwaters has been studied (Laustrup and Toxvig Madsen, 1994). The results were based on 10 years of monitoring of a group of breakwaters. The purpose of the study was to confirm the design theory which had been used and which was based on theoretical computations. The paper confirmed that the use of breakwaters in this group had reduced the need for nourishment landward of the breakwaters by 50%.

Since 1982, the engineering solutions have changed from a hard to a soft approach. There is a number of reasons for this development of which the most important are:

- A growing awareness among the general public and among politicians of environmental issues.

- The problems which required hard solutions have been solved.
- The budgets have been raised dramatically rendering soft solutions more competitive.

Because of the small volumes and the lack of experience of the Danish contractors regarding pumping of sand directly on shore on the North Sea coast, the mobilization costs were quite high and consequently, the unit costs were high. With increasing volumes and experience, a better approach for nourishing the different parts of the profile has been developed. Today, three methods are used. The methods are pumping onshore through a submerged steel pipe, pumping over the bow and dumping from split barges.

3. Evaluation of the effect of the beach nourishment

Some effects of the nourishment have now been evaluated. In this chapter, some of the aspects concerning a steepening of the coastal profile, positioning of the nourishment sand in the profile and the effect of using coarse sand will be discussed.

3.1 Profile steepening

The retreat rates shown in figure 6 have been calculated for the profile section from -6 to +4 m. For nourishment we only use a volume equivalent to the erosion on this part of the profile. As it could be expected, this policy leads to a steepening of the profiles. Figure 8 shows a number of bars each representing a number of profiles on a part of the coast. The length of the bars represents the difference between erosion velocity of the profile seaward of -6 m and landward of -6 m. This difference represents the steepening of the profiles. Before 1986, the steepening took place on parts of the coast where groyne groups had been built (sections 3,4 and 5 in figure 8). After 1986, the steepening mainly took place where the nourishment projects were carried out (sections 1-5 in figure 8).

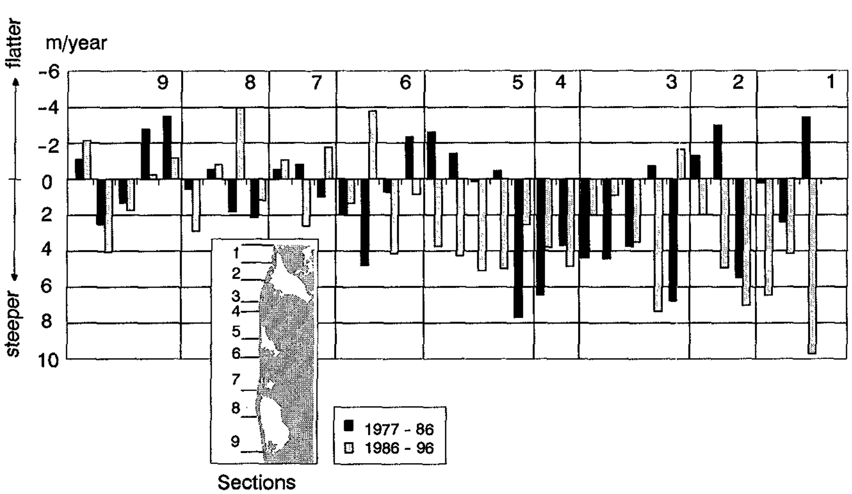

Figure 8. Difference between retreat rates seaward and landward of -6 m

3.2 Positioning the nourishment in the profile

In 1993 - 96, the European Union MAST project Nourtec was carried out with participation from the Netherlands, Germany and Denmark. In the Danish case, a nourishment project on the longshore bar and a project on the beach were studied (Laustrup and Madsen, 1996).

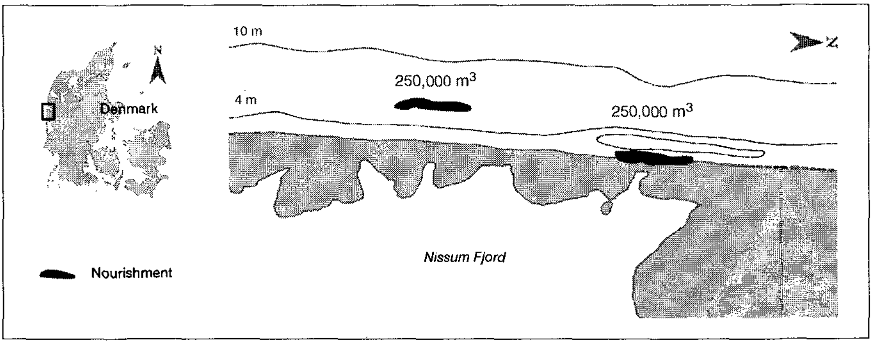

Figure 9. The Nourtec general location plan

The main results were:

- In the first year, the beach nourishment gives the better stabilization of the beach.
- At the end of the period, the shoreface nourishment is the better option for the stabilization of the beach.
- The shoreface nourishment is more stable than the beach nourishment. The main reason is that the shoreface nourishment sand was coarse, $D_{50} = 0.57$ mm. The effect of the beach nourishment is that of a feeder berm and the effect of the shoreface nourishment is that of a breaker berm. The effect of the shoreface nourishment on the outer part of the profile is that of a feeder berm.

The conclusion was that the profile from the bar and out should be nourisbed by dumping sand on the bar. This is also cheaper than placing the sand on the beach. There was nearly no migration of sand from the bar to the beacb so for tbe inner part of the profile it was recommended to place the sand on the beach. Figure 10 shows the principles of positioning tbe sand in the profile that we are going to implement in the future. Part of the nourishment on the beach is used as a buffer to prevent erosion of the dunes during storms.

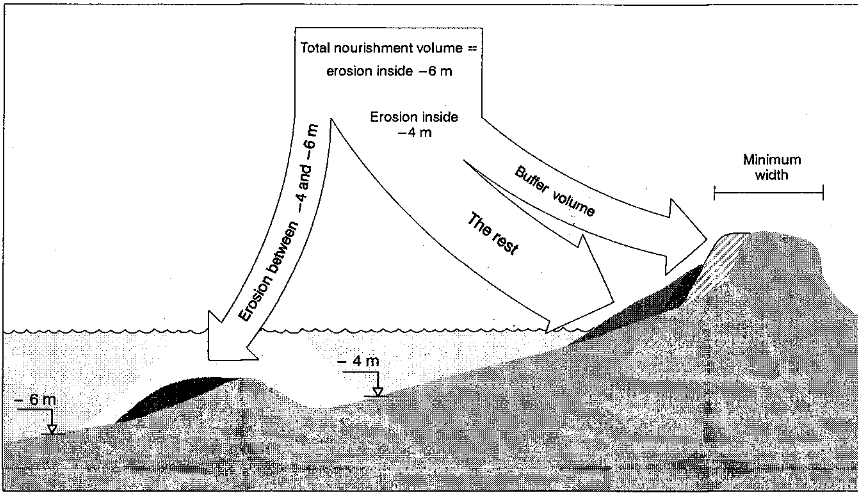

Figure 10. Principles of the positioning

3.3 The effectiveness of coarse sand

We are now studying the relationship between the D_{50} and the effectiveness of the sand. For that purpose, we have evaluated nine projects involving annual nourishment during the period 1986-96. The length of the project stretches are 3-5 km and the volume per metre is 10-50 m^3.

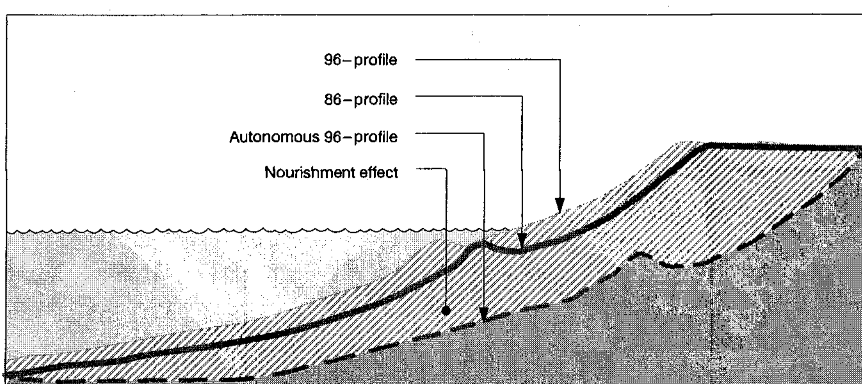

Figure 11. Principles of calculating the nourishment effect

The principle used for the study is shown in figure 11. We know the 1986 and the 1996 profile. However, the effect of the nourishment is the shaded area between the 1996 profile and the autonomous 1996 profile (the profile without nourishment). Since we do not know the theoretical profile and since this profile is important for the result, we have estimated it in three different ways.

①

Natural erosion on section X, 86–96 =
erosion on section X, 67–86 + (erosion on reference stretches, 86–96 – erosion on reference stretches, 67–86)

②

$$\text{Natural erosion on section X, 86–96} = \frac{\text{erosion on reference stretches, 86–96}}{\text{erosion on reference stretches, 67–86}} \bullet \text{erosion on section X, 67–86}$$

③

$$\text{Natural erosion on section X, 86–96} = \frac{\text{CERC–transport, 86–96}}{\text{CERC–transport, 67–86}} \bullet \text{erosion on section X, 67–86}$$

Figure 12. Methods for calculation of the natural erosion rates

Figure 12 illustrates the three methods used to estimate the natural erosion. We are looking for the natural erosion in the nourishment period 1986-96 on each of the nourished stretches.

Method 1 and 2 use the erosion on stretches of the coast which developed naturally and which have the same degree of exposure as the nourished stretches (reference stretches). In method 1, the difference between the period 1986-96 and 1967-86 is used. In method 2, the ratio between the erosion of the two periods is used. In method 3, the ratio between transport capacities calculated by use of the CERC formula in the two periods is used.

Profile erosion 1967–86		79.4 $m^3/m/year$
Difference 1967–86 to 1986–96		–3.2 $m^3/m/year$
Natural erosion 1986–96		76.2 $m^3/m/year$
Effect of breakwaters		–10.1 $m^3/m/year$
Anticipated erosion 1986–96 without the effect of nourishment included		66.1 $m^3/m/year$
Monitored erosion 1986–96		6.2 $m^3/m/year$
Effect of nourishment		59.9 $m^3/m/year$
Nourishment volume		40.3 $m^3/m/year$
Effectiveness of nourishment	59.9/40.3	1.49

Figure 13. Example of the calculation of the effectiveness

Figure 13 shows an example of a calculation of the effectiveness. The effect of the nourishment is the shaded area in figure 11. The nourishment volume is known so the effectiveness is the effect divided by the volume. In this case, it is greater than one. The effectiveness can also be defined as the ratio between erosion velocity in native and borrow material. Since the renourishment factor (James, 1975) is the ratio of erosion velocity in borrow material to native material, this is the inverse of the effectiveness.

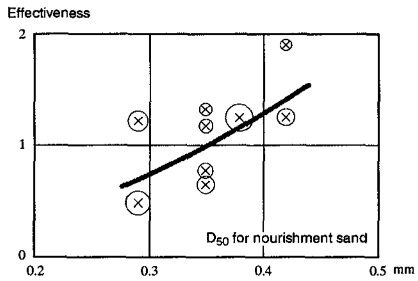

Figure 14. Results of the calculation of the effectiveness using method 1

Figure 14 shows the effectiveness as a function of the D_{50} for the nourishment sand, if we use method 1 to estimate the theoretical profile in 1996. The area of the individual dots is proportional to the nourishment volume. The total volume represented by the dots is 10 mill. m^3. The curve is a weighted best fit curve.

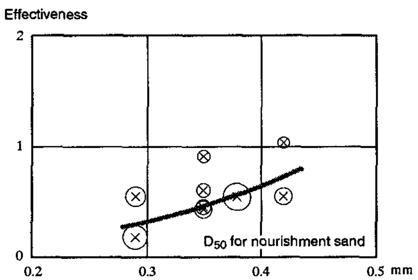

Figure 15. Results of the calculation of the effectiveness using method 2

Figure 15 shows the same relationship if we use the ratio between erosion on reference stretches in the two periods.

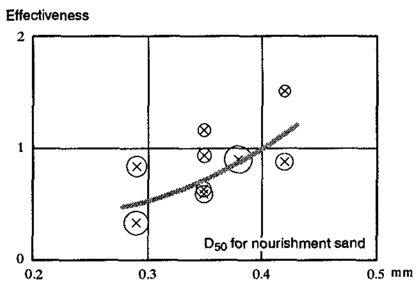

Figure 16. Results of the calculation of the effectiveness using method 3

Figure 16 shows the relationship if we use the ratio between CERC transport capacities for the two periods.

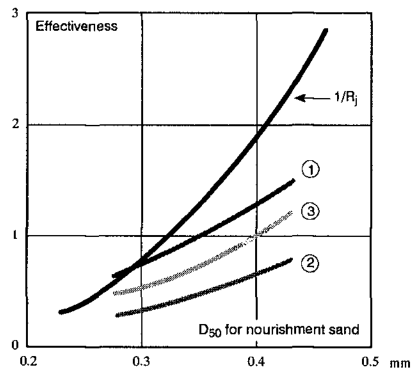

Figure 17. Comparison of the three methods and the renourishment factor

Figure 17 shows method 1, 2 and 3 and the inverse renourishment factor.

To improve the results we are going to work on getting better sediment characteristics and to improve the method to calculate the theoretical erosion. Besides, the comparison with the inverse renourishment factor is not correct if there has been some erosion in the native material in a project. We know that is the case at the beginning of the period 1986-96 because at that time, we did not have enough money to stop the erosion completely, so we are going to do some more work along that line.

4. Conclusions

Erosion control with a combination of nourishment and low detached breakwaters has reduced the retreat rate to average zero for the depth range from -6 m to +4 m. The policy of only nourishing this part of the profile has resulted in a steepening. The safety against flooding has been raised to a return period of more than 100 years by building new dunes and by protecting the dune foot with a revetment.

Based on monitoring of nine nourishment projects with a total volume of 10 mill. m^3 for a period of 11 years, guidelines for positioning of nourishment sand in the profile and for the use of coarse sand in nourishment projects have been developed. Better quality information about the native and borrow sand characteristics is needed.

References

James W. R. (1975). Techniques in evaluating suitability of borrow material for beach nourishment. Report TM60. US Army Corps of Engineers, Coastal Engineering Research Center, Vicksburg.

Laustrup C. and Madsen H.T. (1994). Design of Breakwaters and Beach Nourishment. Proceedings, ICCE 1994, pp. 1359 - 1372.

Laustrup C. and Madsen H. T. (1996). Comparison of Beach and Shoreface Nourishment, Torsminde Tange, Denmark. Proceedings, ICCE 1996, pp. 2927 - 2940.