GOLD COAST 
NEARSHORE NOURISHMENTS 

Final report 

E. Meisner 

August 1991 

Delft University of Technology 
Department of Civil Engineering 
Hydraulic and Geotechnical Engineering Division 
Hydraulic and Offshore Engineering Section
GOLD COAST
NEARSHORE NOURISHMENTS

An investigation into the behaviour and effectiveness of nearshore nourishments, carried out in 1988 and 1989 at the Gold Coast, Queensland, Australia

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PREFACE

This report is the result of a study on the nearshore nourishments at the Gold Coast, Australia, which took place in 1988 and 1989.

The study has been carried out from September 1990 to August 1991, as a part of the master's exam of my Civil Engineering study. During this project I was under the guidance of ir. J.A. Roelvink, a research-worker from Delft Hydraulics and a part-time lecturer at the Delft University of Technology, whom I consulted weekly. Further members of the guidance committee were prof. ir. K. d'Angremond, who was the chairman of the committee, and dr.ir. J. van de Graaff, both from the Hydraulics Division of the Department of Civil Engineering.

Most the work has taken place at the Department of Civil Engineering of the Delft University of Technology. Apart from that I spent a three week period in the Delft Hydraulics Laboratory "De Voorst", during which period I received most of the necessary survey data, together with some software.

Finally, another two weeks were spent in Brisbane and at the Gold Coast, where a number of model computations was performed, using the most recent Kirra wave recordings.

Here I would like to thank Delft Hydraulics, in the person of J.A. Roelvink, for giving me the opportunity to perform this study and for advising me during the course of the investigations.

I would also like to thank the Beach Proteet Authority of Queensland and the Gold Coast City Council for so willingly providing their data and for giving me the opportunity to carry out a part of the study on the spot.

My special thanks go to Mr. Russell Murray from the BPA, for taking care of the necessary arrangements for my stay in Brisbane and at the Gold Coast, and for his advises and background information which helped me a lot during the project.

I sincerely hope that this report will encourage further investigations into the applicability of nearshore nourishments, for I think a lot of benefit is still to be gained from studies on this fairly new method of beach reconstruction.

Edwin Meisner,
SUMMARY

Introduction

The City of Gold Coast, Queensland, on the Australian east coast, contains a few of the continent's most beautiful beaches. Since the late 1960's, however, the southern part of these beaches has suffered from extreme erosion, due to the construction of two training walls in the mouth of the Tweed River, just south of the beaches. Several projects have been undertaken to limit the ongoing beachline recession. A number of groynes was constructed and a small scale beach nourishment was carried out in the 1970's. A small nearshore nourishment was carried out in 1985. These projects provided only very local solutions, so the necessity of more large scale solutions still existed.

In 1988 a large nearshore nourishment was carried out. In September/October 1988 1.5 million m$^3$ of sand was dumped nearshore between the -6m and -10m depth contour, in the most southern part of the Gold Coast beaches. Following these works, carried out by WestHam Dredging, further nourishment took place from November 1989 until May 1990, consisting of the dumping of approximately 3.6 million m$^3$ of sand on the beach profile, from Kirra to Coolangatta. It is the 1988 nearshore nourishment that is the main subject of this report.

Analysis of survey data

Thanks to a comprehensive monitoring programme that was started together with the nourishment project in 1988, bottom height data at a number of dates were available. These data were used to determine the behaviour of the 1988 nearshore nourishment. This was done using profile plots (one-dimensional) from all over the area at different dates as well as two-dimensional difference plots (bottom height differences over a certain period of time, indicating eroded and accreted areas).

The conclusions that can be drawn by interpreting these plots and the differences between them, are:

- The development of a profile, due to the application of the nearshore nourishment, depends largely on the location of the profile in the nourishment area.
- The transport mechanisms that take care of the transport of the nourished sand are combined cross-shore and alongshore transports. Sand, dumped nearshore, is transported shoreward causing increased longshore transport.
- The highest grade of effectiveness in reconstructing the beach is obtained where longshore and cross-shore transport effects both contribute to accretion of the beach. This is from about halfway the nourishment zone toward the end of it, looking in nett alongshore transport direction.
Model computations

The analyses of the survey data have lead to a reasonable good idea of the migration pattern of the nearshore dumped sand. A number of calculations was now performed, using the morphological models UNIBEST-LT and -TC from Delft Hydraulics. Calculated profile changes were compared to the measured reality.

The most important conclusions regarding these model computations, are:

- There is no change in longshore transport rates due to the change of the profile shape.
- There is no gradient in longshore transport along the coast, although the volume calculations had shown a very strong longshore transport differential in the investigated area.
- Different longshore transport formulas show different longshore transport values. From the formulas that have been used (Bailard, Bijker and Van Rijn), only Van Rijn's formula leads to a profile shape dependent longshore transport.
- The cross-shore transport model computations, which were used to determine profile changes due random wave attack, showed the deformation of the nourishment bar rather well. However, they resulted in a somewhat too slow shoreward movement of sediment, while the flattening of the bar took place a little too quickly.
- Although a realistic time series of wave heights and periods had been used as input data, the model does not account for any bar formations, due to storm surges.

The Dutch situation

When the Gold Coast situation is compared to the Dutch local circumstances, a number of differences has to be taken into account, such as less steep profiles, shorter waves and a higher tidal level variation in front of the Dutch coast. Calculating the profile and volume changes with the UNIBEST-TC cross-shore model leads to the following conclusions on the effectiveness of nearshore nourishments before Egmond:

- Under Dutch circumstances a nourished bar will deform in a different way than it will under the Gold Coast circumstances. Due to the flattening out of the nourished bar in time some of the nourished sand will move seaward, where in the Gold Coast situation the migration of nourished sand is coastward only. Therefore the results of the Gold Coast nourishment works should not be extrapolated to the Dutch situation without utmost care and without further study into the local conditions.
- It may take several years for a nearshore nourishment to be effective on the upper beaches. The shoreward movement of nearshore dumped sand before the Dutch coast is at least slower than it is in the Gold Coast situation.
Further study

This study has mainly been an investigation into the qualitative aspects of nearshore nourishments. Further study into more quantitative aspects (nourishment depth, nourishment volumes, real effectiveness, sensitivity analyses) will be necessary in order to make detailed calculations for a nearshore nourishment design and to make a fair comparison with upper beach nourishments.
CONTENTS

PREFACE ................................................................. I
SUMMARY ................................................................. II
CONTENTS ................................................................. V
1. INTRODUCTION ......................................................... 1
2. REASONS AND AIMS OF THE STUDY ................................. 2
3. HISTORICAL REVIEW .................................................. 3
   3.1 The Tweed River training walls ................................. 3
   3.2 The Delft Report ................................................. 3
   3.3 First measures .................................................. 4
   3.4 Re-evaluation of the Delft Report .............................. 4
   3.5 Further measures .............................................. 6
   3.6 Recent nourishments ............................................ 7
      3.6.1 The nearshore dumpings .................................. 7
      3.6.2 Upper beach nourishments ................................ 8
   3.7 Monitoring project .............................................. 9
4. GENERAL APPROACH TO THE INVESTIGATIONS ..................... 10
   4.1 General subdivision of the study .............................. 10
   4.2 Data used ...................................................... 10
      4.2.1 Survey data ............................................... 10
      4.2.2 Wave data ............................................... 11
      4.2.3 Tide data ................................................ 13
5. SURVEY DATA ANALYSES ............................................ 14
   5.1 Introduction ................................................... 14
   5.2 Interpretation of the profile plots ............................ 15
   5.3 Interpretation of difference plots ............................. 18
   5.4 Conclusions .................................................... 20
      5.4.1 Conclusions from the profile plots ....................... 20
      5.4.2 Conclusions from the difference plots ................... 21
   5.5 Volume calculations ........................................... 22
      5.5.1 Introduction .............................................. 22
      5.5.2 Possibilities of transport gradients .................... 23
      5.5.3 Discussion of the results ................................ 23
      5.5.4 Conclusions .............................................. 24
6. MODEL COMPUTATIONS ................................................ 26
   6.1 Introduction ................................................... 26
   6.2 Data used and restrictions .................................... 26
   6.3 Longshore transport calculations .............................. 28
      6.3.1 Expectations .............................................. 28
      6.3.2 Results and interpretations .............................. 29
<table>
<thead>
<tr>
<th>Section</th>
<th>Subsection</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3.3</td>
<td>Conclusions</td>
<td>31</td>
</tr>
<tr>
<td>6.4</td>
<td>Cross-shore transport calculations</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>6.4.1 Introduction</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>6.4.2 Results of the calculations</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>6.4.3 Conclusions</td>
<td>34</td>
</tr>
<tr>
<td>6.5</td>
<td>Sensitivity analysis</td>
<td>35</td>
</tr>
<tr>
<td>7.</td>
<td>THE DUTCH SITUATION</td>
<td>37</td>
</tr>
<tr>
<td>7.1</td>
<td>Introduction</td>
<td>37</td>
</tr>
<tr>
<td>7.2</td>
<td>Approach and input data</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>7.2.1 Data</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>7.2.2 Profile calculations</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>7.2.3 Effectiveness</td>
<td>38</td>
</tr>
<tr>
<td>7.3</td>
<td>Results</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>7.3.1 Profile development</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>7.3.2 Effectiveness</td>
<td>41</td>
</tr>
<tr>
<td>7.4</td>
<td>Conclusions</td>
<td>43</td>
</tr>
<tr>
<td>8.</td>
<td>GENERAL CONCLUSIONS</td>
<td>44</td>
</tr>
<tr>
<td>9.</td>
<td>FURTHER STUDY</td>
<td>45</td>
</tr>
<tr>
<td>9.1</td>
<td>Introduction</td>
<td>45</td>
</tr>
<tr>
<td>9.2</td>
<td>Further survey data analyses</td>
<td>45</td>
</tr>
<tr>
<td>9.3</td>
<td>The UNIBEST models</td>
<td>45</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>48</td>
<td></td>
</tr>
</tbody>
</table>

APPENDICES:

A. Maps
B. Xl,Y1 co-ordinate system
C. Profile plots
D. Difference plots
E. Depth contour plots
F. The 'RANRAN' interpolation program
G. Mathematical-physical description of the UNIBEST models
H. Longshore transport plots
I. Cross-shore development plots
J. Volume calculations (Erosion/Accretion)
K. Egmond nearshore nourishment
L. Sensitivity study results
M. Tugun wave climate at -15m depth contour
1. INTRODUCTION

The city of Gold Coast, Queensland, on the Australian east coast, contains a few of the most beautiful recreational beaches of the continent. However, since the construction of two new training walls in the mouth of the Tweed River, just south of Gold Coast in the state of New South Wales, from 1962 to 1964, the southern Gold Coast beaches have suffered from extreme erosion (see Figure A.1).

Several projects have since then been undertaken to limit the beachline recession. The most recent and until now most comprehensive beach restoration performances are gathered in the "Southern Gold Coast Beach Nourishment Project". Stage I of this project, which has been completed in 1990, consisted of the dumping of about 3.6 million m³ of sand along the southern Gold Coast beaches.

Prior to this, the dumping of 1.5 million m³ of sand in the nearshore area, between Coolangatta and Bilinga, was carried out by the Gold Coast City Council in 1988 (see Figure A.2). This nearshore nourishment is the main subject of the study.

The study is meant to be an investigation into the behaviour and effectiveness of the nearshore nourishment at the Gold Coast. Also a comparison will be made between the Gold Coast and the Dutch situation.

In Chapter 2 of this report the reasons for carrying out this study will be given as well as the aims of the study. Chapter 3 is a historical review of the Gold Coast beach erosion problems from 1964 to the present. A description of the approach to the investigations will be given in Chapter 4. The investigations themselves, which can be divided into a visual and a computational part, are described in Chapters 5 and 6.

The Gold Coast situation will be compared to the Dutch situation in Chapter 7, where the possibility of nearshore nourishments in front of the Dutch coast will be discussed. General conclusions from this study are included in Chapter 8. Finally a number of suggestions for further study into this matter will be given in Chapter 9.

A list of references is included at the end of this report. The numbers between square brackets in the text indicate the numbers belonging to the literature in the reference list.

A lot of figures have been used in this study. However, most of these figures have not been included in the text of this report, but in the Appendices A to L at the end of the report. Wherever necessary, one is referred in the text to the figures in the appendices.
2. REASONS AND AIMS OF THE STUDY

The economy of the City of Gold Coast depends to a large extent on tourist activities, associated with its recreational beaches. Therefore a number of more or less successful efforts have been undertaken to limit the ongoing beachline recession and so to make safe their main source of income.

The 1988 Gold Coast City Council nearshore nourishment and the Southern Gold Coast Beach Nourishment Project, being the largest projects so far to perform beach restorations, consist not only of the dumping of sand on the beach profile, but also of a comprehensive monitoring programme and an investigation into the coastal processes.

In order to be able to make an optimal design of nearshore nourishments in future projects, it is important to have insight in the behaviour of nearshore dumped sand.

Delft Hydraulics is presently conducting the investigations into the Gold Coast beach erosion problems, co-operating with the Beach Protection Authority (BPA) of Queensland and the Gold Coast City Council (GCCC). In a joint project with the Delft University of Technology a study of the nearshore nourishments at the Gold Coast has been carried out by one of the University's students. The report on this study will be presented as the thesis of the author's master's exam.

The aims of this study were, first, to determine the migration pattern of the nearshore dumped sand. This was done by visualizing the bottom changes in the coastal area, using survey data that became available thanks to the monitoring programme; and second, to verify the morphological models UNIBEST-LT and UNIBEST-TC from Delft Hydraulics, by comparing the results of the data analyses to the results of numerical calculations. From various sides (the Dutch Public Works, dredging companies) there has been a great demand for inquiries into the possibility of nearshore nourishments in front of the Dutch coast. Therefore the third aim of this study is to try to extrapolate the results, valid for the Gold Coast situation, to the Dutch situation.
3.1 THE TWEED RIVER TRAINING WALLS

The City of Gold Coast, Queensland, Australia, extends as a relatively narrow strip of development along about 30 kilometres of coastline. The shoreline consists of sandy beaches with several controlling rocky headlands. The economy of the City depends to a large extent on tourism associated with these popular recreational beaches.

At the south of this area, near the border between Queensland and New South Wales, the Tweed River entrance is located (see Figure A.1).

The Tweed River is a tidal river with, under normal conditions, a low fresh water discharge. For the benefit of the increasing amount of shipping two training walls were built in the mouth of the river in 1904. These walls resulted in some minor accretion on the south of the river and also in a bar of sand in front of the river mouth. By 1960 the accretion had progressed to such an extent that the walls lost their function. For that reason from 1962 until 1964 the construction of two new training walls took place. The new walls extended until approximately 450 metres from the existing shoreline (see Figure A.2). Again there was accretion at Letitia Spit, the beach just south of the river. At the same time, erosion of the Gold Coast beaches occurred north of the Tweed River.

3.2 THE DELFT REPORT

By order of the Co-ordinator's-General's Department in Queensland in the late 1960's Delft Hydraulics produced a report on the situation in 1970. The longshore transport conclusions in the "Delft Report" were based upon visual observations from ships, the K.N.M.I.-data. The results of the investigations were very surprising. The natural sediment transport at Letitia Spit (see Figure A.2) was about 500,000 m$^3$ per year northward, while at Tugun, on the other side of Point Danger, it was about 200,000 m$^3$ per year and at The Spit, 28 km to the north of Point Danger, it was again about 500,000 m$^3$ per year. They concluded there was a "loss" of sediment somewhere near Point Danger and that, although no evidence had yet been found, there had to be a lot of accretion somewhere offshore of Point Danger [1,6].

The recommendations stated in the "Delft Report" were [see 15]:

1. Extensive sand nourishment (7 million m$^3$) along the Gold Coast from Coolangatta to The Spit (see Figure A.1) to restore the beaches.
2. Annual replenishment to offset the losses (300,000 m$^3$/year).
3. Construction of training walls atCurrumbin Creek and the Nerang River entrance (see Figure A.1).

3.3 FIRST MEASURES

In the 1970's various projects were carried out to provide local solutions to the erosion problems at the southern Gold Coast (see Figure A.2). To limit the ongoing beachline recession rock seawalls were constructed at Coolangatta and Kirra. Also a groyne was built at Kirra Point in 1972 to restore Coolangatta's surfing beach. Erosion of the beach just downdrift of Kirra Point continued and during strong storms in 1974 the seawall was destroyed. It was built up again to protect the properties in that area. That same year, 1974, a second groyne was constructed at Kirra (the Miles Street Groyne) in order to retain a usable beach in front of the Kirra Surf Lifesavers' Clubhouse. At the same time a beach nourishment of approximately 800,000 m$^3$ was applied on Kirra Beach with sand from the Tweed River. Since the borrow pit of this nourishment was located in the morphologically active zone of the river, the nourishment was only of short term benefit. The pit has been infilled with sand from the longshore transport along Letitia Spit. Further erosion of the beaches took place.

3.4 RE-EVALUATION OF THE DELFT REPORT

In 1981 the Beach Protection Authority of Queensland undertook a re-evaluation of the longshore transport rates. The longshore transport gradient conclusions stated in the 1970 Delft Report were strongly questioned for various reasons [see 1]:

- The calculations were based only upon wave data, obtained by visual observations;
- The accretion in offshore areas near Point Danger was still unproven;
- The rate of accumulation of sand updrift of the Kirra Point groyne indicated a longshore sand transport closer to 500,000 m$^3$ per year than the 200,000 m$^3$ suggested in the Delft Report.

For the new calculations they were able to use accurate wave data, recorded during the previous ten years with the BPA Wave Rider equipment. To illustrate the differences between the KNMI-data and the newly recorded data, Figure 3.1 has been included. It shows the percentage of occurrence of the peak energy periods for all heights and all directions in both situations.
Two different techniques were used for the computation of the longshore sediment transport: The Bijker method, which was also used in the Delft Report, and the method using the C.E.R.C. equation.

The results of these calculations were in some aspects different from the results from 1970. The rates of longshore transport at Letitia Spit and at The Spit were about the same as those in the Delft Report (500,000 m³ per year). But instead of being 60% less, the longshore transport at Tugun appeared to be about 500,000 m³ per year as well. The results from the re-evaluation of 1981 are given in Table 3.1:

<table>
<thead>
<tr>
<th>Location</th>
<th>Bijker</th>
<th>C.E.R.C.</th>
<th>Delft Report</th>
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<tr>
<td>Letitia Spit</td>
<td>411,000</td>
<td>500,000</td>
<td>478,000</td>
</tr>
<tr>
<td>Tugun</td>
<td>475,000</td>
<td>426,000</td>
<td>176,000</td>
</tr>
<tr>
<td>The Spit</td>
<td>495,000</td>
<td>530,000</td>
<td>485,000</td>
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Table 3.1: Longshore transport rates in m³ per year.

The conclusions stated in the 1981 report [1] were:

a. No natural longshore transport differential of any importance exists in the investigated area;
b. Further expansion of the Tweed River training walls will lead to serious erosion problems;
c. There is no 60% loss of transported sediment near Point...
Danger, as was said in the Delft Report;

d. The erosion of the beaches is concentrated immediately
downdrift of the training walls. The total volume of sand
involved is estimated to be 7 million m$^3$ until the late
1980's, while the natural yearly transport of sediment is
about 500,000 m$^3$.

e. The erosion of the beaches that have not been effected by the
Tweed River training walls or other groynes, has mainly been
caused by storms. This storm erosion can result in short term
fluctuation of the beachline. Developments situated too close
can be threatened during these erosion cycles and therefore
an adequate buffer zone has to be established, either by
relocation of the properties or by beach nourishment;

f. Beach nourishments from sources outside the beach system
would provide a long term benefit for the Gold Coast beaches;

g. To reinstate former beach conditions immediate nourishment of
about 2 million m$^3$ in the Palm Beach/Burleigh area and a
minimum of 4 million m$^3$ in the Tugun/Point Danger area would
be necessary in 1981. To maintain this situation with little
or no future beachworks, re-establishment of the original
natural longshore transport of sand past the Tweed River is
required;

3.5 FURTHER MEASURES

Various options were considered in 1983 [3]:

- Restore the beaches, by building offshore breakwaters or
groynes and/or carrying out nourishments at the southern
Gold Coast.

- Construct a marina and/or pier seaward of the boulder wall,
between Kirra and Bilinga.

 Restoration of the beaches was considered to be the most
desirable option. Since all structural solutions require the
nourishment of sand to replace all former losses, the
nourishment solution (only) appeared to be the cheapest
solution.

While investigations were being carried out, a small scale
nourishment was applied by the GCCC at North Kirra, in front of
the North Kirra Lifesaving Clubhouse, in 1985. An amount of
215,000 m$^3$ of sand was put down onshore and 100,000 m$^3$ nearshore
(see Figure A.2).

Monitoring of this small scale nourishment and the use of
schematic representations of typical Kirra bed topographies had
shown that the nearshore nourishment shoreward of the -9m depth
contour (Reference Level -9m) translates shoreward and that
although there was rapid smoothing of the individual dredge
dumps, the deeper sections (to R.L.-10m) reacted slowly to gross
sediment transport forces [3].

As the investigations had shown, depletion of the whole active
profile could be expected (to approximately 10m below sea-
level). Therefore the tender documents for further nourishment


in the Kirra area in 1988 specified nourishment of the whole beach profile, from the beach to R.L.-10m. However, an option of nearshore nourishment only was included. Since nearshore nourishment only had the cheapest tender prices, it was decided to accept the tender of WestHam Dredging P/L of 1988 to carry out these works, which would provide, with time, a usable beach.

3.6 RECENT NOURISHMENTS

3.6.1 The nearshore dumpings

The most recent nourishment works at the Gold Coast have been carried out during a period of almost two years. Starting with the nearshore nourishment in September 1988 by the GCCC, the works went on as Stage I of the Southern Gold Coast Beach Nourishment Project until the end of May 1990. A total amount of 5.1 million m$^3$ of sand was deposited in different parts of the coastal area. See Figure A.3 for an illustration of the nourishments, described below.

First nearshore dumping

At first a large nearshore nourishment was carried out in September/October 1988 by WestHam Dredging, an Australian-based company, which is a daughter-company of two Dutch dredging companies (Boskalis-Westminster and H.A.M.), and which was contracted by the Gold Coast City Council. They used the "W.H. Resolution", a trailing suction hopper dredge, with bottom doors to discharge the material (see Figure 3.2). The sand was dredged from the inactive zone, from R.L.-20m to R.L.-30m, at about 1500m offshore (see Figure 3.1). A total of 1.5 million m$^3$ of sand, which was measured in the hopper, was dumped between R.L.-6.5m and R.L.-10.5m over a length of about 1.5km, between Coolangatta and Bilinga (Area I on Figure A.3). This was all done in a nine week period. The works lasted from mid-September to November 1988 and attracted a 25% State Government grant. Monitoring of these works has been undertaken by the Gold Coast City Council.

![Figure 3.1 The "W.H. Resolution" dredging the sand](image)
Second nearshore dumping

Because all of the Gold Coast nourishment projects seemed to be successful so far in improving the beach amenity for use by tourists and local residents, further nourishments were carried out in 1989 and 1990 as Stage I of the Southern Gold Coast Beach Nourishment Project.

Further nearshore nourishment took place in November 1989. As a result of a new contract WestHam deposited about 0.4 million m$^3$ of sand, again using the "W.H. Resolution". The sand was dumped immediately along coast to the north of the 1988 dumping, between R.L.-6.5m and -10.0m, forming a 2km northward extension of the 1988 works, between Bilinga and Tugun (Area II on Figure A.3). The dredge area was adjacent to the 1988 dredge area 1 to 2km offshore, consisting of 'inactive' sand sources.

3.6.2 Upper beach nourishment

After the nearshore nourishment works were completed, the dumping of 3.2 million m$^3$ on the upper beaches began in January 1990. These upper beach nourishments were also carried out by WestHam, this time using the "HAM310" dredge.

A pipeline connection from the dredge pump-out was established at about the southeastern limit of the latest offshore deposition area.

First, from January to March 1990, 2.0 million m$^3$ of sand was pumped onto the beach via longshore extensions of the pipeline at a rate of about 600 m$^3$/m, between the end of the last nearshore dumping and halfway the first one (Area III). After that, another 100,000 m$^3$ was pumped on the north of this area (Area IV), and another 50,000 m$^3$ on the south of it (Area V). This was in March/April 1990.

Finally 1.05 million m$^3$ of sand was deposited just north of Kirra Point in May 1990 (Area VI).
3.7 MONITORING PROJECT

Included as a part of Stage I has been a large monitoring project. It is considered essential that the nourishments be monitored in detail, so that its behaviour and effectiveness can be properly assessed. This information is very useful in understanding the ongoing erosion and accretion of the recreational beaches in the region. It also provides insights for the planning of further future nourishment projects, to be carried out as Stage II of the present works, of which the timing and details have not yet been established.

The monitoring project covers a range of procedures, each aimed to provide important data and information on different aspects of the coastal processes and beach response in the area. It consists of (see [4]):

- wave height recordings and analyses (at Kirra, The Spit and in deepwater);
- wave direction analyses;
- hydrographic surveys (swimmer or jet-ski lines, comprehensive surveys, radial lines);
- aerial photography;
- sediment sampling and analyses;
- current metering and analyses;
- Cope-recordings (comparison of the analyses to information obtained by measurements in similar, non nourished, sites).

The monitoring and analyzing of the coastal processes will continue throughout 1991 and 1992. Ongoing analyzing of the data and reporting is proposed by the BPA.
4. GENERAL APPROACH TO THE INVESTIGATIONS

4.1 GENERAL SUBDIVISION OF THE STUDY

As has been said in the description of the study objectives (Chapter 2), the investigation into the Gold Coast nearshore nourishments can be divided into two parts. The first part consists of the processing of the available survey data, obtained within the scope of the monitoring programme. These data have been used to produce different sorts of bottom height plots:

A. One-dimensional:
   - Plots of bottom profiles along the coastline, indicating changes of the cross-shore profiles in time.

B. Two-dimensional:
   - Depth contour plots, indicating the position of depth contours in the investigated area at certain moments.
   - Difference plots, indicating differences between bottom height values on two different dates. This gives the possibility to see whether and where any erosion or accretion has taken place in the period between the two dates.

The second part of the investigations consists of the use of the morphological models UNIBEST-LT and UNIBEST-TC, developed by Delft Hydraulics, to calculate longshore and cross-shore transport rates. With this a comparison can be made between numerically and visually analyzed coastal processes and conclusions can be drawn with regard to the applicability of the models.

Furthermore a number of model computations has been carried out to explore the possibility of nearshore nourishments in front of the Dutch coast. This final issue is not meant to be a study in depth, but it tries to encourage further investigations into this relatively new and rather poorly understood method of coast protection.

4.2 DATA USED

4.2.1 Survey data

The data that have been used for analysis purposes and for processing in different programs consist mainly of bottom height data and wave climate data.

The bottom height data consist of depth values along the Gold
Coast shore, from the upper beach until approximately RL-15m, measured by the GCCC surveyors. At regular times the bottom height is measured by echoing from survey ships along a number of survey lines. The survey lines have been collected in different sets of lines, such as Eta-lines, Kirra-lines (K-lines), radial lines and a number of other sets of lines which will not be discussed here. To get an idea of the density of the survey lines, Figure A.4 of the appendices gives a review of all the survey lines used in the investigated area (from Point Danger toCurrumbin).

Not all of the survey lines have been measured at the same dates. Each time a survey job was carried out by the GCCC surveyors sections of the total field of survey lines were measured. The survey data that were useful in this study are the measurements along the K-lines (K1.0 to K37.0) and along some of the Eta-lines (Eta14.0 to Eta25.0). These lines, spaced about 100m, cover the entire investigated area from Coolangatta to Tugun (see Figure A.2). Data of different dates were available, which made it possible to make a comparison between the bottom heights on different moments in time.

Survey data were available from 1966 to 1991. From 1966 (right after the construction of the Tweed walls) to 1987 (a year before the comprehensive nourishment works commenced) there was about one complete survey, covering the entire investigated area, every five years. From October 1988 till the present the survey works were carried out more often. Since the start of the 1988 nourishment works complete surveys have been carried out every three to five months as a part of the monitoring program (see Section 3.7). This means that the bottom height in the entire investigated area is measured along survey lines, from the upper beach until approximately -15m.

The survey data, measured by the GCCC, are collected on large BPA master files. From these files the data that were useful have been extracted and adapted for this study. The data that were mainly used were from the following dates:

- September 1987
- November 1988
- April 1989
- July 1989
- November 1989
- January 1990

How the data have been processed for this study will be discussed in the next chapter.

4.2.2 Wave data

The wave climate data were necessary as input into the morphological models, calculating sediment transport rates. The Gold Coast wave climate, assessed for the "Delft Report"
from 1970 was based largely on visual observations from ships and lighthouses (the KNMI-data). More accurate data have been recorded in the subsequent decade in Southeast Queensland, using the BPA's Waverider equipment, located near Point Lookout (the "Brisbane station", 87 km north of Point Danger, see Figure A.1). These data, included in the 1981 BPA report on the Gold Coast longshore transport [7], have been used together with other recordings and directional assessments by Delft Hydraulics to perform comprehensive refraction calculations in 1990 [9]. The results of these calculations, among which is the Tugun wave climate at the -10m depth contour, have been used to derive the Tugun wave climate at the -15m depth contour (see Appendix M). This wave climate, which was used as input to calculate sediment transports, is given in Table 4.1. The following remarks can be made to this table:

a. The given directions are the angle to the shore normal of wave incidence related to the Tugun coast orientation ('+' equals a clockwise angle).
b. The total number of days equals 284, which means that on 81 of the 365 days a year the wave heights were zero or very calm and therefore not significant for the present study.

<table>
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</table>

Table 4.1 Tugun wave climate at -15m depth contour
Subsequent to the calculations using the Tugun wave climate, assessed for the entire investigated area from Coolangatta to Tugun, more recently recorded wave data were used as well. One of the BPA's Wave Rider buoys, located at the -16m depth contour, about 1.5km offshore of Kirra (see A.2), recorded the wave heights and periods near Kirra, from 1988 to 1990. The adapted recordings have been used as a time series of wave heights ($H_5$) and periods ($T_p$) with four registrations a day, from December 1988 to January 1990. Since it consisted of about 1500 measurements, the time series itself has not been included in this report.

4.2.3 Tide data

Finally, concise tide data have been used as well. In both longshore and cross-shore transport calculations a variation of the sealevel has been taken into account. A semi-diurnal tidal variation of $+0.60$ m was accepted, which was simplified to a periodic time series of the waterlevel (period 1.03 days), given in Figure 4.1:

![Figure 4.1 Simplified tidal level variation](image)
5. SURVEY DATA ANALYSES

5.1 INTRODUCTION

As was said earlier, the first part of the investigations consisted of the determination of morphological changes, by analyzing and plotting the bottom height data. This was done, either by using the data directly from the data files, or by using interpolated bottom height values. The sets of bottom height data at different dates, irregularly divided in the investigated area, have been interpolated to a regular grid of co-ordinate points (see Appendix B, Figure B.1), in order to produce iso-depth contours and difference plots, which will be discussed later on. A special interpolation program, called 'RANRAN', was used (see Appendix F).

By means of the profiles and the difference plots the changes of the nearshore bottom with time could be made visible.

Cross-shore bottom profiles

The profile plots, included in Appendix C, have been produced by using the data of a number of survey lines, from different dates. The dates that provided the most complete sets of survey data (data from all over the investigation area) and that therefore have been chosen to use in the analyses, are:

- September 1987, one year before the 1988 nearshore nourishment was carried out;
- November 1988, right after the nearshore nourishment works had been completed;
- July 1989, nine months after the 1988 nourishment works had been completed;
- January 1990, thirteen months after the 1988 nourishment, and right after the second nearshore nourishment of 1989 had been completed, but before the upper beach nourishments had commenced.

Cross-shore bottom profiles from the above mentioned dates on different locations along the coast have been compared in order to determine the effect of the 1988 nearshore nourishment. Ten different survey lines, spaced about 400m, have been chosen to use to draw the profiles. They are: K1.0, K6.0, K10.0, K16.0, K21.0, K24.0, K28.0, K32.0, K36.0 and Eta22.0.

The location of these survey lines, with respect to the location of the nourished areas, is shown in Figure C.1 of the appendices.

Difference plots

The difference plots, included in Appendix D, have been produced
by subtracting the bottom heights from different dates from each other and plotting the new values to show, with the help of colours, whether and where there had been a loss or accretion of sand in the coastal area.

Plots have been made from height differences in the following periods:

- 1966 to 1972
- 1972 to 1989
- September 1987 to November 1988
- November 1988 to April 1989
- November 1988 to July 1989
- November 1988 to November 1989
- November 1988 to January 1990

In most difference plots November 1988 has been chosen as the reference date, for this was very shortly after the completion of the 1988 nearshore nourishment.

The colours in the difference plots vary from red to green, respectively indicating erosion and accretion in the period between the two dates of which the bottom height values have been subtracted.

**Depth contour plots**

The third type of plots that have been produced are depth contour plots, included in Appendix E. Bottom contours on all the dates at which survey data were available, starting on September 1987, have been drawn. This resulted in contours on September 1987, October and November 1988, April, July and November 1989 and January 1990.

The depth contour plots did not have an important function in the analyses, but were necessary to determine any possible errors in the bottom height data field. These errors could be caused either by errors in the data files, or by interpolation errors. Wrong survey data were removed from the data files.

**5.2 INTERPRETATION OF THE PROFILE PLOTS**

The profile plots have been included in Appendix C, as Figures C.2 to C.11. The boulder wall, constructed along the upper beach, from the Coolangatta groyne to the K30.0 survey line, is marked on these plots, as well as the reference sea level.

On ten different places along the investigated area (see Figure C.1) cross-shore profiles of different dates have been compared. The differences between the profiles are discussed below.

**K1.0**

- Clearly there is a wrong data point at about 500m from base in the 09/87 plot.
- The position of the 07/89 profile is a little too
high. This may be due a systematic error, occurred during the survey.
- Between 550 and 850m from the base point of K1.0 the bottom dumping of September/October 1988 is shown clearly in the 11/88 profile.
- On 07/89 the bump has flattened out partially and it has moved shoreward a little. Now it is located between 400 and 850m. In 01/90 the erosion of the bottom dumping has continued.
- Some accretion has taken place between 11/88 and 07/89 in the area from 50 to 400m from the base point.
- Between 07/89 and 01/90 some of the accreted sand has been eroded again.

K6.0:  
- It is very clearly indicated that there is not much of a beach left in this area. The water has reached the boulder wall already in 09/87. However, the erosion does not continue in the subsequent period.
- The dumping area extends from about 650m to 950m from the base point of K6.0.
- The irregularities in the dumping have disappeared in 07/89 and some erosion of the bump has taken place between 07/89 and 01/90.
- There has been some accretion of sand between 11/88 and 07/89 in the area between 200 and 400m from the base point of K6.0.
- A relatively large amount of sand has been eroded from the beach area (between 100 and 250m from the base point) between 07/89 and 01/90.

K10.0:  
- Only three profiles can be seen on this plot. The 11/88 profile is the same as the 09/87. An error must have occurred during the survey data processing, or during storing the data in the master files, by which the 09/87 data of survey line K10.0 were also stored as 11/88 data.
  This has, however, great consequences for the interpretation of the contours and the difference plots in the next sections, as will be discussed later on.
- It is shown that a lot of erosion of the upper beach has taken place between 09/87 and 07/89. This erosion did not continue in the period after that.
- Erosion has taken place between 07/89 and 01/90 in the area between 100 and 400m.

K16.0:  
- First thing to notice is that the cross-shore volumes on 09/87 and 11/88 are completely different. Part of this difference is of course due to the nearshore dumping between 400 and 850m from the base point, but part of it could be due to alongshore transport of sand from other areas.
- The irregular shape of the bottom dumping of November 1988 is shown clearly.
- The bottom dumping is flattening out between 11/88
and 07/89. (This considers the area between 400 and 800m from the base point of K16.0.)

- Between 11/88 and 07/89 the beach area accreted significantly. Between 07/89 and 01/90 this area has suffered from erosion again, so that more than a year after the nourishment works the beach is still on the same level as it was before.
- Between 07/89 and 01/90 the bottom beyond 400m from the base point stays at a constant level.

K21.0:  
- Erosion of the upper beach has taken place between 09/87 and 11/88.
- The sand, dumped in September/October 1988, between 400 and 700m, which is shown as a bump in the 11/88 profile, is transported shoreward after 11/88.
- The bump has flattened out, and the beach area (50 to 200m from the base point) has accreted between 11/88 and 07/89 and also between 07/89 and 01/90.
- No bottom changes have taken place beyond the dumping area (beyond 700m from the base point of K21.0).

K24.0:  
- This profile plot shows more or less the same development as the last one (K21.0).
- Erosion of the upper beach has occurred between 09/87 and 11/88 (from 0 to 200m from the base point).
- No changes occurred after 11/88 beyond the bottom dumping area, which extends from 400 to 650m from the base point of K24.0.
- In the beach area (between 50 and 150m from the base point) accretion took place from 11/88 to 07/89 and continued to take place from 07/89 to 01/90.

K28.0:  
- First thing to notice on this plot is the shifting of the 09/87 profile of about 30m with respect to the other profiles in this plot. This is shown at the deep water end of the profile, where the four lines should show great similarity since not much morphological activity takes place in that area.
- Accounting for this shifting, the erosion of the upper beach zone between 09/87 and 11/88 is not as bad as it seems to be on the plot. Nevertheless, some erosion has occurred in this period.
- The survey line is located at the northern end of the 1988 nourishment, which is also the southern end of the 1989 nourishment. The first dumping is shown on the 11/88 profile (between 350 and 600m), the second one is shown on the 01/90 profile (between 400 and 600m).
- In 07/89 the bump of 11/88 has flattened out a great deal.
- Between 11/88 and 07/89 the beach area, between 50 and 150m from the base point, has suffered from some erosion. In 01/90 the beach is back on its old level, due to accretion in this area between 07/89 and 01/90.
K32.0: - No data from 09/87 were available from this survey line.
- The upper beach area (between 50 and 150m from the base point) eroded at first (from 11/88 to 07/89) and accreted in the second period (from 07/89 to 01/90).
- The 1989 nourishment is shown clearly to be located between 450 and 600m from the base point of K32.0.

K36.0: - Again no survey data from 09/87 were available.
- However this survey line is not located in the first nourishment area, there has still been some accretion between 11/88 and 07/89 in the area between 300 and 450m from the base point of K36.0.
- The beach area (between 0 and 150m from the base point) suffered from great erosion in the period between 11/88 and 07/89, but accreted from 07/89 to 01/90.

Eta22.0: - The Eta-lines have been surveyed in November 1987 instead of in September 1987, as have been the K-lines. However, both surveys are treated as one and therefore the 11/87 survey was used here.
- Between 11/87 and 11/88 not much happened to the upper beach, between 200 and 400m from the base point. However, accretion occurred between 450 and 650m. Comparing the cross-shore volumes leads to the conclusion that sand must have been transported alongshore.
- Between 11/88 and 07/89 some small accretion occurred between 500 and 700m from the base point of Eta22.0.
- In the same period severe erosion took place in the beach area, between 250 and 350m from the base point.
- The second offshore dumping can be seen on the 01/90 profile, between 600 and 800m from the base point.
- The rest of the 01/90 profile is nearly the same as the 07/89 profile, which means no further erosion of the profile has taken place between 07/89 and 01/90.

5.3 INTERPRETATION OF THE DIFFERENCE PLOTS

The difference plots are included in Appendix D, as Figures D.1 to D.7. Figures D.1, D.2 and D.3 have been produced with data from before the 1988 nearshore nourishment, to show the development of the bottom in the period from the construction of the Tweed River walls to the start of the nourishment works in 1988. Most of the difference plots, however, show the bottom height at a certain date related to the reference date November 1988. With this the bottom changes after the completion of the 1988 nearshore nourishment are shown.

One remark has to be made to the Figures D.3 to D.7: As was said in Section 5.2, at the discussion of survey line K10.0, the data from 11/88 from that survey line were not the
correct data. Later analyses showed that also the K11.3 data from 11/88, at about 100m north of the K10.0 data in the Kirra North section (see difference plots), were actually from 09/87. These errors in the data field which had not been detected before the difference plots were produced, have caused slight irregularities in the difference plots. Figures D.3 to D.7 show the differences related to the 11/88 situation. The results shown in the Kirra North section on these plots are therefore not reliable.

The seven difference plots are discussed below.

1972 - 1966 (Figure D.1):

The period from 1966 to 1972 was a period before the construction of the groynes at Kirra. Therefore the coastal development was caused by natural alongshore and cross shore transports, influenced by the Tweed River training walls. The green area in the Bilinga and Tugun sections indicates an accretion of sand in the beach zone, possibly partially at the cost of eroded sand in the more seaward zone, indicated by the orange area. The Coolangatta and Kirra sections, however, show a clear erosion of the beach zone, extending about 600m seaward. These areas, located just beyond Point Danger, clearly suffered most from the construction of the training walls.

1989 - 1972 (Figure D.2):

In 1972 and 1974 the groynes were built in order to restore the Coolangatta and Kirra beaches. They had indeed a positive local effect on these beaches (green areas). But at the same time the erosion of the beaches north of the groynes at Bilinga and Tugun grew worse (orange/red areas), also as the effect of the Tweed River training walls extended. It is also very clearly indicated where the 1988 nearshore dumping has taken place. The large green bar, 600 to 800m offshore, shows the area in which the bottom level has risen after the nourishment.

11/88 - 09/87 (Figure D.3):

The nearshore nourishment is visible as a green bar about 600m offshore. The Kirra North section shows unreliable results, as was said earlier. It is also shown that in the upper beach area from the Bilinga South section northward, erosion has occurred in period between 09/87 and 11/88. The dark green bar adjacent to the eroded beach in the Bilinga South section is due to the movement of the sand bank, as is shown on the profile plots (Figures C.2 to C.11).
It is clear that the nearshore dumping of September/October 1988 is now indicated mainly by an orange coloured area. This means that the nourishment bump has flattened out a great deal. Near Kirra some erosion has taken place. Further to see are two green bars around an orange one just outside the coastline. The most seaward green bar and the orange bar can be interpreted as a sand bank that has moved from the coast. This can be proved by looking at the profile plot from e.g. K21.0. The sand bank appears to move seaward in time. Whether this process is entirely natural, or a result of the nourishment, is not yet evident. The green bar closest to the shoreline, however, is obviously the result of some accretion between November 1988 and April 1989, near the Bilinga South section.

The same that could be seen on the 04/89 - 11/88 plot can be seen on this difference plot. The nourishment has flattened out further and the accretion on the shore has developed further in the direction of Bilinga North.

The most important thing to see on this picture is that the green bar near the shoreline in the Bilinga North section is now getting greener, compared to the last plots, which means the accretion is growing.

January 1990 is a date that is after the second nearshore nourishment, immediately north of the first one. The dredging and dumping had been carried out during November 1989. On this plot the green bar offshore in the Bilinga North section indicates clearly where the dumping has taken place. It is also clear to see that the accretion on the shore, represented by the green bar, is still growing in the direction Bilinga North. On the other hand the yellow/orange bar near Kirra indicates a loss of sand in the period between November 1988 and January 1990 in that particular zone.

5.4 CONCLUSIONS

5.4.1 Conclusions from the profile plots

In general one can see that the development of a profile, due to
the application of the nearshore nourishments, depends on the location of the profile in the nourishment area.

The cross-shore profiles closest to the southern end of the nourishment area show some amount of accretion in the upper beach area in the period right after the bottom dumping. This may be caused by shoreward cross-shore transport of nourished sand. However, after more than one year after the dumping, not much of the accreted sand is left and erosion has already occurred again. This process can be seen best on the profile plots K1.0 to K16.0 (Figures C.2 to C.5).

The profiles located halfway along the nourishment area show a somewhat different development in time. The accretion process in the upper beach zone after the bottom dumping still continues after more than a year. This may be caused by northward alongshore transport of earlier accreted sand south of these profiles. That could also be the reason why at the same time accretion is not shown on more southern profiles: No longshore transport of sand from the zone southern of these profiles has been possible, since no accretion due to cross-shore transport has occurred in that area in the period before.

Finally, the profiles at the very end of the first nourishment area and the profiles north of it, all show that after initial erosion in the period right after the dumping, accretion, or at least no further erosion, has taken place after more than a year. This could be explained by the fact that no or not enough sand has been put on the profile to take care of enough shoreward cross-shore sediment transport to cause accretion of the upper beach zone in that area right after the nourishment. This accretion could occur, however, as an effect of the earlier mentioned alongshore transport of sand accreted on the upper beaches in the area just south of the area considered here.

So, by looking at the profile plots, it could be concluded that the sand, dumped nearshore, is indeed affecting the beach area in a positive sense. The best effect is obtained where cross-shore transport and longshore transports of earlier accreted sand both cause accretion of the beach. This is the area from halfway along the nourishment toward the northern end of it. How this process takes place is given in diagram in Figure C.12 in the appendices.

5.4.2 Conclusions from the difference plots

Clearly the 1972 - 1966 difference plot shows accretion of the upper beach zone north of the Kirra North section. In the same period the Tweed walls were causing severe erosion south of this area, at Coolangatta, leading to the construction of the groynes. Subsequently, the Bilinga and Tugun beach accretion process was stopped and turned into an erosion process. The trend now was an eroding beach.
However, this trend was turned around after the application of the nearshore nourishments. After November 1988 the process of erosion of the Bilinga beaches was stopped and even some accretion took place. As is shown on the difference plots 0489-1188 to 0190-1188 (Figures D.3 to D.6), the accreted beach zone is growing northward with time. This can be explained by alongshore transport of sand in the nearshore zone, that has been transported shoreward, due to cross-shore transport of nearshore nourished sand.

The conclusions drawn in Section 5.4.1, regarding the profile plots are also valid for the difference plots. This could have been expected, of course, since the same data were used in both cases, but it is encouraging to obtain the same results and conclusions in two different ways.

The conclusions regarding the behaviour of the nearshore dumped bar are shown schematically in Figure C.12.

5.5 VOLUME CALCULATIONS

5.5.1 Introduction

In addition to the analyses in this chapter a number of volume calculations have been carried out. The bottom height data, interpolated to the X1, Y1 grid points (see Appendix B), were used to calculate the cross-shore volumes per section of 100m along the X1-axis from Y1=0 until Y1=1500m. Volumes at different dates were subtracted, and the volume differences have been plotted in Figures J.3 to J.6 of Appendix J. This gave an opportunity to see whether accretion or erosion had occurred in the considered section during the period between two dates.

With the volume changes a calculation was made of the transport through each section in a certain period. For example: When the change of volume in a section of 100m during six months is equal to +10,000m$^3$, the average transport of sand into the section has been 10,000/0.5 m$^3$/year bigger than the average transport out of the section. Assuming that no sediment is transported through the seaward boundary of the section (see Figure 5.1), and defining 'longshore transport' as the transport of sediment parallel to the X1-axis, positive in northward direction, all volume changes in the section are caused by a longshore transport differential over the section. In the example this means a difference in longshore transport rates of 20,000 m$^3$/year between the northern and the southern boundary of the section.
Fig. 5.1 Transport in and out of a section

The transport differentials over all of the sections, from \( X_1=1250 \) m towards \( X_1=4300 \) m, have been added up and plotted in the bottom pictures of Figures J.2 to J.4. These pictures do not show absolute transport rates, but 'relative' longshore transport rates, relative to the transport at \( X_1=1250 \) m.

5.5.2 Possibilities of transport gradients

In Figure J.1 of the appendices three different possibilities of wave directions are given (from the north, east and south-east), together with the expected longshore transport gradient in each of these situations.

Although it is assumed that the annual average longshore transport in the investigated area is northward - as is proven by history - this does not mean that in a few months the average transport cannot be in another direction. For example, if the waves are coming from the north in a certain period this will cause an alongshore transport of sand in southern direction (see Figure J.1).

Nevertheless, from wave climate data it can be derived that on the average the waves between Kirra and Tugun are coming from east to north-east (see also Table 4.1). However, the Gold Coast area is known for its south-eastern storms. In Figure J.1 it is also shown that a south-eastern storm can cause a large transport gradient between Coolangatta and Tugun, due to the screening effect of Point Danger.

The possibilities of the wave directions in Figure J.1 have been used at the interpretation of the results of the volume calculations and the relative transport rates (Figures J.2 to J.5).

5.5.3 Discussion of the results

The first figure, J.2, shows that at the northern area, with low
X1 co-ordinates, there has been some erosion from 11/88 to 04/90. But at the southern end of the nourishment zone (higher X1-values) a lot of accretion has taken place between approximately 2500 and 4000m. This would mean a very strong longshore transport gradient in that area, with a slope as is shown. Whether the transport is directed northward or southward, so whether the highest transport rates occur at the northern or at the southern end of the area, cannot be derived from the longshore transport diagram, since the transport rates are only relative to the transport at the northern end. It depends on what average direction the wave were coming from between 11/88 and 04/89. Since no directional wave data from that period are available (yet), no conclusions regarding this aspect can be drawn as yet.

The second figure, J.3, shows a different trend. In nearly all the sections erosion has occurred between 04/89 and 07/89, as is shown in the top picture of this figure. This means that again there has been a strong gradient in the longshore transport, but now causing erosion, in stead of accretion.

As was described earlier on (see Figure J.1) waves coming from the south-east will cause a transport gradient comparable to the one in Figure J.3. It is very plausible that a severe south-eastern storm which took place in April 1989 may have caused a great deal of the erosion in the area between 04/89 and 07/89, due to the strong gradient in longshore transport.

The third figure, J.4, shows that some accretion has occurred as well as erosion in the northern end of the nourishment zone, indicating a changing longshore transport gradient, as is shown is the bottom picture. The shape of the average longshore transport curve in the period from 07/89 to 11/89 is about the same as the shape in Figure J.1, but the differences between the values are much smaller.

The fourth figure, J.5, shows a lot of accretion in the northern end of area, due to application of the 1989 nearshore nourishment. No information about longshore transport rates can be derived from this figure, since the sand has been added to this area in the period from 11/89 to 01/90 by man.

5.5.4 Conclusions

It is clear that there is no equilibrium of sand volumes in the considered area (from X1=1250 to X1=4300). In the first period after the 1988 nearshore nourishment part of the area, especially the southern part, has accreted. North of that zone erosion has taken place. This might indicate the southward movement of sand, due to wave attack from the north (see Figure J.1).

The erosion, as indicated in Figure J.4, can be due to south-eastern wave attack, such as south-eastern storms, like the one that took place in April 1989. The entire area suffered from
some erosion, due to the longshore transport gradient. The sand must have been moved to other areas to the north. By 11/89 the accretion (shown in Figure J.5) may be caused by northward movement of the nourished volumes, as was stated in Section 5.4.

In general it can be stated that there is a clear variability in the transport gradient. The average yearly transport may be in northward direction, but still the direction can vary between certain periods, depending on the direction of wave attack. This can cause situations that are temporarily different from the average situation.
6. MODEL COMPUTATIONS

6.1 INTRODUCTION

One of the objectives of this study was the verification of morphological models UNIBEST-LT and UNIBEST-TC, developed by Delft Hydraulics, with respect to the migration of nearshore nourished sand volumes. This was done by comparing model computations results to the results from the survey data analyses (Chapter 5).

The models that are involved are part of the program-package UNIBEST, which stands for UNiform BEach Sediment Transport. All modules of this package consider sediment transports (and in some cases also morphological changes) as are expected to occur along a coast which locally may be considered uniform in alongshore direction.

The module UNIBEST-LT computes alongshore sediment transports on a static, but otherwise arbitrary profile of a sandy coast. The driving of the longshore current is due to obliquely incident, random waves and/or a tidal current.

The module UNIBEST-TC computes the development in time of an arbitrary cross-shore profile of a sandy coast, due to cross-shore sediment transports. The cross-shore transport is induced by different cross-shore currents, which are calculated as a function of a random time series of obliquely incident waves.

For a detailed mathematical-physical description of the models one is referred to Appendix G.

6.2 DATA USED AND RESTRICTIONS

In order to use the above mentioned models to calculate sand transports and profile changes, input data were necessary. The input data can be subdivided into three different sets of data:

a. Cross-shore profile data (bottom height values):
   It was chosen to use cross-shore profiles in the model computations, that had been used in the survey data analyses as well (Chapter 5): K1.0, K6.0, K16.0, K21.0, K24.0, K28.0 and Eta22.0 (see Figure C.1). This provided the opportunity to make a fair comparison between measurements and calculations.

b. Wave data (and mean sea level variation):
   The wave data which were used consisted of the Tugun wave
climate (1981), mentioned in Chapter 4 (Table 4.1), and the Kirra time series of waves, recorded from 1988 to 1990 (see Chapter 4).
Since the longshore transport calculations needed a directional wave climate as input, the Tugun waves were the only waves assessed for these calculations. However, both Tugun and Kirra waves were used in the cross-shore transport calculations.
Furthermore a (simplified) tidal level variation was used in both longshore and cross-shore transport computations (see Chapter 4).

c. Specific parameters:
The transport formulations, described in Appendix G, which are used in the models, account for a number of specific parameters, such as wave parameters, sediment parameters and formulation coefficients. In the tables below (Table 6.1 and Table 6.2) the values assessed for these specific parameters are given for both longshore and cross-shore transport calculations.
Note that the values for the efficiency coefficients $\epsilon_b$ and $\epsilon_s$ (which are used in Ballard's transport formula, see Appendix G) have been chosen to be respectively 0.20 and 0.04, although 0.10 and 0.02 are more generally accepted values. However, the advised values by Delft Hydraulics for longshore transport are 0.20 and 0.04. In this study the higher values have been assessed for both longshore and cross-shore transport calculations.
In Section 6.5 the sensitivity of the cross-shore calculations to the choice of the efficiency coefficients is discussed.

<table>
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Table 6.1 Specific parameters used with UNIBEST-LT
As has been stated earlier on, in Section 5.4.1, the alongshore transport of sediment seems to increase as a result of shoreward migration of the nearshore dumped sand. It may be expected that, especially in the zone where the waterline had reached the boulder wall before the first nearshore dumping (see for example the profile plots of K16.0 and K21.0, Figures C.7 and C.8), the longshore transport capacity will increase when sand has been moved onto the beach. Since in other areas the longshore transport capacity will be lower (as is shown in Figure 6.1 below), this will cause erosion of the newly accreted sand at the south side and accretion at the north (see Figure 6.2). In other words: the newly accreted sand will move alongcoast in time (displacement D in Figure 6.2).
The velocity of the movement of the additional sand along the coast depends on the amount of nourished sand involved in a cross-shore profile. An amount of $\delta A$ m$^3$/m of sand is transported along the coast with a velocity $v$, calculated by:

$$ v \text{ (m/year)} = \frac{\delta S \text{ (m$^3$/year)}}{\delta A \text{ (m$^3$/m)}} $$

This means that in a period of $\delta t$ years (e.g. 0.5 years) the displacement of the sand is $v*\delta t$ (m).

In the difference plots of Appendix D a movement of about 150m in nine months can be distinguished (from April 1989 to January 1990). The velocity of the movement of the bar therefore is $150/0.75 = 200$ m/year. Assuming, for the moment, that all of the nourished sand is moved shoreward, this means an average volume ($\delta A$) of about 500 m$^3$/m (1.5 million m$^3$ over a length of 3km). With this the difference in longshore transport capacity ($\delta S$) should be $200*500 = 100,000$ m$^3$/year. If the original longshore transport rate would be about 500,000 m$^3$/year (as stated in the 1981 BPA report [7]), this would mean an increase of about 20%.

6.3.2 Results and interpretations

The model UNIBEST-LT has been used to calculate the longshore transport rates, integrated over a year, on different locations along the coast, on different dates. The dates of which the profile data, discussed in Section 6.2, have been used are:

- September 1987 (a year before the first nearshore nourishment)
- November 1988 (right after the nourishment)
- July 1989 (8 months later)
- January 1990 (14 months later, and right after the second nearshore dumping)

The wave climate used in the computations was the Tugun wave climate, mentioned in Section 6.2, which has been discussed in Chapter 4. This wave climate has been assessed for the entire
area from Coolangatta to Tugun. This means implicitly that the coastline is assumed to be straight.

The longshore transport formulas that have been used are the formulas of Bailard, Bijker and Van Rijn. For a detailed description of these formulas one is referred to Appendix G.1.

The results of the calculations are given in Table 6.3.

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Table 6.3 Longshore transport rates in thousand m³ per year

The values, given in Table 6.3, have been plotted in four different figures, included in Appendix H, Figures H.1 and H.2. The following interpretations can be given to these figures:

a. The first thing to notice on the figures of H.1 and H.2 is that none of the calculations answers to the expectations, mentioned in the previous section. There is no clear "S" to be distinguished in any of the plots.

b. In all calculations the transport formula of Bailard predicts the lowest longshore transport rates of the three formulas that have been used. The longshore transport is, according to Bailard, about 200,000 m³ per year, virtually independent of the profile shape, only being influenced by the wave climate.
which has been described in section 4.2.
The longshore transport rates, predicted by Bijker's formula, are approximately twice as high as those, predicted by Bailard. Still the values seem to be independent of the shape of the cross-shore profile.
The third transport formula, Van Rijn's, predicts the highest longshore transport rates of the three formulas used.

6.3.3 Conclusions

None of the used transport formulas leads to results that are comparable to the expectations, stated in Section 6.3.1. Of course this can be due to the use of the Tugun wave climate for the entire investigated area. Implicitly a straight coast has been taken into account, but it is plausible that the curvature of the coast which has been neglected in the calculations, will cause an alongcoast variation in height and direction of the wave climate. This could for example be due to diffraction and screening effects around Point Danger. Also there may be some different currents due to the curvature of the coast, other than the at the locally straight coast as assumed in the model.

It could also be that the model is not entirely valid for the situation that is considered. It could be that some of the assumptions that have been made, regarding the specific parameters mentioned in Section 6.2, are not entirely valid. The sensitivity of the model to changes of the specific parameters has been investigated and included in Section 6.5.

6.4 CROSS-SHORE TRANSPORT CALCULATIONS

6.4.1 Introduction

The data used in the cross-shore model computations have been discussed in Section 6.2. They consisted of cross-shore profile data, wave data and specific parameters.

Two sets of wave data have been used:

a. A time series of waves at RL-15m, derived from the 1981 Tugun wave climate (Table 4.1), as it had been calculated by Delft Hydraulics [9]. This time series does not contain any storm wave data, which may be a great disadvantage in
calculating the profile changes.

b. A time series of waves, recorded between 1988 and 1990 by the BPA's Waverider equipment at approximately RL-16m, 1.5km offshore of Kirra. This time series provided detailed information about wave heights and periods near Kirra between the completion of the 1988 nourishment and January 1990.

The starting profiles were from November 1988. These initial profiles were used to calculate the profiles on July 1989 and on January 1990. The calculated profiles were then compared to the measured profiles on the same dates.

6.4.2 Results of the calculations

The results of the profile calculations have been included in Appendix I. Figures I.1 to I.7 show the results with of the calculations with the Tugun waves. Figures I.8 to I.13 show the results of the calculations with the Kirra waves. For each of the considered profiles the results of the comparison between measured and calculated profiles are discussed below. In some of the figures it is shown that the cross-shore volumes of the measured and calculated profiles are not always equal. This is caused by the fact that the calculated profiles are determined assuming conservation of sediment in cross-shore direction. This conservation is not always found in the real situation, due to migration of sediment other than cross-shore (see also Chapter 5).

First the results of the computations using the 1981 Tugun wave climate are discussed, and after that, the results from the computations using the recently recorded Kirra time series are discussed wherever there turned out to be an inducement to do so.

Results with 1981 Tugun wave climate (Figures I.1 to I.7):

K1.0: The resemblance between the measured and the numerically determined profile of July 1989 is nearly perfect. The shapes of both profiles are quite similar. On January 1990, 14 months after the initial profile, the resemblance is still pretty good, although the calculated profile shows a little too high a beach.

K6.0: The flattening process of the offshore bar has taken place a little too fast in the calculations. The shape of the measured and calculated profiles, however, are rather alike. The most striking differences are again found just below the waterline. The model calculations have taken no account of the sand bank that is a part of the profile of January 1990.
K16.0: What could be seen in the figure of K6.0, the sand bank that was not shown in the calculated profile, is even more obvious in this figure. The deformation of the nourishment bar is calculated relatively well, but more shoreward the differences between measured and calculated profile become greater.

K21.0: The same that has been said about K16.0 can be said about K21.0. The accretion in the beach zone, that has been measured in July 1989, is not found in the calculated profile. Also the sand bank has disappeared completely during the calculations. The cause of this phenomena will be discussed later on.

K24.0: This figure shows differences between measured and calculated values that are quite substantial. First of all, the calculated profiles do not account for the sand bank, shown in the measured profiles; and second, the erosion of the offshore dumped bar has taken place too rapidly in the calculations.

K28.0: Contrary to the K24.0 calculations, these calculations have provided results that are reasonably comparable to the measured values, again with the exception of the sand bank. This counts for both the profiles of July 1989 and January 1990. (The seaward bump on the measured profile of 01/90 is due to the second nearshore nourishment.)

Eta22.0: Although this profile is located beyond the 1988 nourishment zone (see Figure C.1), it has been used in order to determine the autonomous evolution, as it is computed by the model. This shows the profile changes that occur during the calculations, without the presence of a nearshore bar. It is clear that also in this situation the sand bar formation is not found in the calculated profile, and that there are significant differences between the calculated and measured profiles.

The survey lines K32.0 and K36.0, which have been investigated as a part of the survey data analyses in Chapter 5, have not been included in the cross-shore transport calculations. The 1988 nearshore nourishment extended until approximately K32.0 (see Figure C.1), so that the calculation of the two mentioned survey lines would not have provided any information about the development of the nourishment in time. However, for completeness sake, Eta22.0 has been chosen to process in the model.
Results with 1988 Kirra wave recordings (Figures I.8 to I.13):

Since the results of these calculations are generally equal to the previous results, the profiles will not be discussed separately again. Only a few general comments will be given on the most striking differences.

The most important thing to notice is that the formation of a sand bar is again not calculated by the cross-shore model, even though the wave data input is a realistic time series of wave heights and periods. Furthermore it is shown that the model sometimes tends to flatten out the nourishment bar a little quicker than in the real situation, but also that the shoreward migration of the nourished sand takes place a little slower in the model computations than in the real situation. This aspect is not as clear in the first set of calculations as it is in the second.

6.4.3 Conclusions

First of all the profile evolution in the nourished situation does not seem to differ a lot from the autonomous evolution, as it is calculated by the model.

Further conclusions can be drawn with respect to: (a) The speed of the profile development in the model computations, compared to reality. And (b) The profile shape produced by the model, compared to reality.

As to the first aspect it can be concluded that in the computations performed in this study, the nourishment tends to move shoreward a little slower than in reality, although the flattening of the nourished bar is sometimes calculated reasonably well. The movement of the nearshore dumped sand in the model computations is only shoreward, as it is in the reality, shown on the profile plots (Figures C.2 to C.11). No nourishment sand is 'lost' in deeper water.

As to the second aspect, concerning the profile shape, it can be concluded that the model does not account for any sand bars, formed on a profile due to wave attack. The general assumption that sand banks are formed during storm situations leads to the expectation that in the first set of calculations, which used an average wave climate without storm waves, the storm bar development would not be calculated by the model. However, the second set of calculations, using a real time series of wave heights and periods, should have produced somewhat more realistic results. This, now, did not happen.
6.5 SENSITIVITY ANALYSIS

In order to determine any effects of the (sometimes arbitrary) choice of the input data on the results of the calculations, a brief study has been carried out.

Two aspects have been investigated:

a. The effect of the bottom slope on the longshore transport rates, calculated by the different formulas.

b. The effect of the (sometimes arbitrary chosen) constants in the calculations, like the bed roughness and the efficiency factors on transports and profile changes.

The first aspect has been investigated by carrying out a number of model calculations, using the 1981 Tugun wave climate. Except for the cross-shore bottom profile, all input data have been kept the same. The bottom was chosen to be straight and inclined, with a varying slope.

The results of these computations, included in Appendix L, Figure L.1, showed that Van Rijn's longshore transport formulation produces results that are indeed slope-dependent. The steeper the profile slope, the higher the longshore transport rates, calculated with Van Rijn's formula. This may be the cause of the different results obtained with Van Rijn's formula in the longshore transport calculations, discussed in Section 6.3.

The results, calculated with Bijker's and Bailard's formula seem to be virtually independent of the profile slope, although they both show a very slight tendency towards higher longshore transport rates on less steep profiles.

The investigation into the second aspect, concerning the influence of the choice of some of the specific parameters on the computation results, consisted partly of a literature study. This study made clear that none of the formulations used is very sensitive to any (slight) changes of the specific parameters, except for Bijker's formula, which is relatively sensitive to changes of the bottom roughness height (r).

Furthermore a cross-shore computation has been carried out to determine the effect of the choice of the efficiency factors (εₕ and εᵢ) in the formulations of Bailard. In this study the factors have been chosen to be respectively 0.04 and 0.20, in both longshore and cross-shore transport calculations, following the advise from Delft Hydraulics for longshore transport calculations. Although 0.02 and 0.10 are more generally accepted values for cross-shore transport calculations, it was decided to use the same coefficients in all calculations in this study. As a sensitivity study on this aspect survey line K16.0 has been re-calculated with the lower efficiency factors, the results of which are given in Figure L.2 of the appendices.

As was expected lower efficiency factors cause a lower cross-shore transport of sediment (see Bailard's formulation, Appendix G.2). However, it is obvious that the choice of different
efficiency factors in Bailard's cross-shore transport formula does not have a very big effect on the shape of the calculated profile (Figure L.2), which could indicate that the profiles are close to the equilibrium shape.
7.1 INTRODUCTION

One of the study objectives was to extrapolate the results from the Gold Coast nearshore nourishment study to the Dutch situation. From various sides there has been a great demand for investigations into the desirability of nearshore nourishments in front of the Dutch coast. Although the general opinion is that nearshore nourishments are less expensive but also less effective than ordinary upper beach nourishments, no clear answer has yet been given to the question if, when and how nearshore nourishments should be applied.

In order to encourage further investigations into this matter, this chapter deals with a brief study into an imaginary nearshore nourishment, located in front of the Egmond coast in the Netherlands. This study is not meant to be a thorough investigation, but tries to predict the behaviour of a nearshore nourishment under Dutch circumstances, using the cross-shore model UNIBEST-TC to calculate the profile changes.

7.2 APPROACH AND INPUT DATA

7.2.1 Data

The cross-shore profile that is considered in this study is the cross-shore profile number 40, the 'Egmond profile'. The starting profile on which the imaginary nearshore nourishments have been applied (see fig. K.1), was measured on 20 June 1984 (a 'JARKUS'-survey).

The wave data that were used in the model computations were recorded at Survey Station Noordwijk, from January to December 1984 and consisted of a time series of wave heights (H_{rms}), periods (T_p) and assessed directions (derived from wind information).

The still water level variation was also given as a time series and therefore included in the computation data.

Furthermore a number of specific parameters was used. These parameters are listed in Table 7.1 on the next page. The efficiency coefficients in the formulation of Bailard (\(\varepsilon_b\) and \(\varepsilon_r\)) have been kept the same as in the Gold Coast situation (respectively 0.20 and 0.04), although the more general accepted values are twice as low (0.10 and 0.02). To determine the effect of the choice of the efficiency factors two additional calculations have been carried out using these lower efficiency factors: A calculation of the development of the profile with
the nourishment at location 2 (see Figure K.1) and a calculation of the autonomous evolution (without a nourishment).

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</thead>
<tbody>
<tr>
<td>$\gamma$</td>
<td>wave-breaking index</td>
<td>0.75 [-]</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>wave-breaking coefficient</td>
<td>1.00 [-]</td>
</tr>
<tr>
<td>$f_\text{w}$</td>
<td>bottom friction factor</td>
<td>0.01 [-]</td>
</tr>
<tr>
<td>$k_{\text{BLS}}$</td>
<td>bed roughness</td>
<td>0.05 [m]</td>
</tr>
<tr>
<td>$\epsilon_\text{b}$</td>
<td>eff. coeff. bottom transport</td>
<td>0.20 [-]</td>
</tr>
<tr>
<td>$\epsilon_\text{s}$</td>
<td>eff. coeff. suspended transport</td>
<td>0.04 [-]</td>
</tr>
<tr>
<td>$W$</td>
<td>sediment fall velocity</td>
<td>0.025 [m/s]</td>
</tr>
<tr>
<td>$D_{\text{sed}}$</td>
<td>grain diameter</td>
<td>250 [$\mu$m]</td>
</tr>
<tr>
<td>$\rho_\text{s}$</td>
<td>density of sediment</td>
<td>2650 [kg/m$^3$]</td>
</tr>
<tr>
<td>$\rho_\text{por}$</td>
<td>sediment porosity</td>
<td>0.40 [-]</td>
</tr>
<tr>
<td>$\tan \phi$</td>
<td>tangent of inter. friction angle</td>
<td>0.63 [-]</td>
</tr>
</tbody>
</table>

Table 7.1 List of specific parameters for Egmond situation

7.2.2 Profile calculations

Using the 1984 Egmond profile, supplied with a nearshore nourishment, as a starting profile, the development of the profile was calculated with the UNIBEST-TC cross-shore model. Calculations were performed to determine the profiles six months after the nourishment, one year after and two years after. The results of these calculations have been included in Appendix K and will be discussed later on in this chapter.

In the calculations the nearshore dumping was placed at three different locations on the original profile. These locations are illustrated in Figure K.1. The first location is between NAP-8m and NAP-12m, the second location is between NAP-6m and NAP-10m, which is about the same depth as where the Gold Coast nearshore dumpings were carried out, and the third location is between NAP-2.5m and NAP-6.5m. The nourishments consist of the dumping of about 800m$^3$/m of sand on each of the locations.

The results of the calculations have been included in Figures K.2 to K.5.

The results of the calculations with lower efficiency factors have been included in Figures K.6 and K.7.

7.2.3 Effectiveness

Additional to the development in time of the cross-shore bottom profile including a nourished bar, also a number of volume calculations have been carried out. This was done in order to determine the effectiveness of a nearshore nourishment, as a
comparison to the study carried out by Roelvink in 1988 [8].

The effectiveness can be defined as the change of the crossshore volume in a certain zone, due to the application of the nourishment, as a percentage of the total nourished volume. In this study the definition of the effectiveness is a little different from the one used by Roelvink.

Roelvink defined the effectiveness as the percentage of the nourished volume that is found in a certain zone after a certain period of time, related to the situation without a nourishment. However, in this study the effectiveness is calculated as the ratio of the change of volume in a certain zone, after a certain period, related to the situation right after the dumping, and the total nourished volume.

One effect of this other definition is that the effectiveness in a zone which contains the entire nourishment bar will be calculated as zero, while in Roelvink's study this would be 100%.

The formulation of the effectiveness is therefore as follows:

\[
\text{Eff.}(t,b) = \frac{\delta V(t,b)}{A} \tag{7.1}
\]

in which: \( \text{Eff.}(t,b) \) = effectiveness of nourishment in percentage of nourished sand in a zone \( b \) in a time period \( t \) [%];

\( \delta V(t,b) \) = change of cross-shore volume in zone \( b \) in time period \( t \), calculated by the model and corrected for the volume changes in the autonomous evolution (without the nourishment), calculated by the model [m3/m];

\( A \) = cross-shore volume of nourishment [m3/m];

\( t \) = period of time after the nourishment [years];

\( b \) = zone in which the volume change is calculated (from the upper beach to \( b \) meters seaward).

The zones considered in this study are:

- From the beach to 200m seaward;
- From the beach to 400m seaward;
- From the beach to 600m seaward;
- From the beach to 1000m seaward.

The effectiveness is calculated after 6 months, after 1 year and after 2 years, starting with the initial profiles.
7.3 RESULTS

7.3.1 Profile development

The profiles that have been calculated are the profiles six months after the nearshore nourishment, one year after and two years after. The profile development of the different situations is shown in Appendix K, figures K.2 to K.5.

The following remarks can be made to the figures:

First the autonomous evolution has been calculated in order to determine modeling effects (Figure K.2), which can be subtracted from the calculation results of location 1, 2 and 3, discussed below. It is clear that even in a situation without a nearshore nourishment the model computations show a lot of accretion on the upper beach. This emphasizes the necessity of drawing conclusions from the calculations with utmost care.

Location 1: It was expected that a nearshore nourishment at this depth would respond very slowly to wave-induced cross-shore flows. This is what can be seen in Figure K.3. Two years after the nourishment the nourished bar has only been transformed slightly. Another aspect that attracts the attention is that the migration of sand is not only shoreward. The flattening of the bar takes care of the movement of some of the nourished sand in seaward direction, whereas in the Gold Coast situation all of the nourished sand was moved shoreward.

Location 2: The second location that was chosen for the nearshore nourishment gives about the same results as the first one, except that the flattening process is carried out a little quicker (see Figure K.4). Still the process is relatively slow. In the profile after two years an irregularity is shown at about 2300m. This is due to instability of the numerical process, that may have occurred during the last part of the calculations. This instability has probably no negative effect on the development of the rest of the profile.

Location 3: The third location is close to the shoreline, so it could have been expected that a nourishment at this depth would cause a lot of accretion in the upper beach zone. This is shown in Figure K.5. Some irregularities are shown at 2500m, probably due to instability of the numerical process, but this does not effect the development of the rest of the profile.

The results obtained with the lower efficiency coefficients (Figures K.6 and K.7) show that the shape of the calculated profiles is about the same as it was with the higher coefficients. However, the flattening of the nourishment bar has
taken place a little slower. (This could have been expected since the transports are about half as big with half as high coefficients, see the formula of Bailard in Appendix G.2.)

7.3.2 Effectiveness

From the volume calculations, performed within the cross-shore model computations, the effectiveness of the nearshore nourishment can be given as a function of the location and the time after the dumping. The results of these calculations are stated in Tables 7.2 to 7.5:

<p>| Location 1: 800 m$^3$/m between NAP-8m and -12m, $\epsilon_b=0.20$, $\epsilon_s=0.04$ |</p>
<table>
<thead>
<tr>
<th>Zone</th>
<th>After 6 months</th>
<th>After 1 year</th>
<th>After 2 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 200m</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0 - 400m</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0 - 600m</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0 - 1000m</td>
<td>5</td>
<td>7</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 7.2 Effectiveness (%) of a nourishment at Location 1

<p>| Location 2: 800 m$^3$/m between NAP-6m and -10m, $\epsilon_b=0.20$, $\epsilon_s=0.04$ |</p>
<table>
<thead>
<tr>
<th>Zone</th>
<th>After 6 months</th>
<th>After 1 year</th>
<th>After 2 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 200m</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0 - 400m</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0 - 600m</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0 - 1000m</td>
<td>14</td>
<td>15</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 7.3 Effectiveness (%) of a nourishment at Location 2

<p>| Location 3: 800 m$^3$/m between NAP-2.5m and -6.5m, $\epsilon_b=0.20$, $\epsilon_s=0.04$ |</p>
<table>
<thead>
<tr>
<th>Zone</th>
<th>After 6 months</th>
<th>After 1 year</th>
<th>After 2 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 200m</td>
<td>19</td>
<td>33</td>
<td>25</td>
</tr>
<tr>
<td>0 - 400m</td>
<td>38</td>
<td>41</td>
<td>29</td>
</tr>
<tr>
<td>0 - 600m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 - 1000m</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.4 Effectiveness (%) of a nourishment at Location 3

Note that in this table no effectiveness is given for the wider zones in this situation. The nourishment location is until approximately 500m from the waterline, which means it is completely inside the 0 - 600m zone. Therefore nothing can be
said about the movement of sand from the nourishment within that zone.

The results of the calculations of a nourishment at Location 2, using the lower efficiency coefficients, are given in Table 7.5:

<p>| Location 2: 800 m³/m between NAP-6m and -10m, ( \epsilon_b=0.10, \epsilon_s=0.02 ) |</p>
<table>
<thead>
<tr>
<th>Zone</th>
<th>After 6 months</th>
<th>After 1 year</th>
<th>After 2 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 200m</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0 - 400m</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0 - 600m</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0 - 1000m</td>
<td>10</td>
<td>11</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 7.4 Effectiveness (%) of a nourishment at Location 2, using lower efficiency coefficients

As can be seen in the tables, a nearshore nourishment beyond NAP-6m does not seem to be very effective in the first 600m from the shoreline, at least not in the first two years after the dumping.

When applied at relatively shallow water, nearshore dumped sand can apparently be effective in the first 400m, but the effectiveness will decrease after more than a year after the dumping.

It should be well noted that these effectiveness values have only been meant to give an indication of the real effectiveness. As can be seen in Figure K.2, a lot happens to the profile during the model computations, even without the presence of a nearshore nourishment. This result should be a reason to be very careful when interpreting the other results and drawing conclusions.

The choice of lower efficiency coefficients influences the results mainly as far as the velocity of the profile development is concerned. It does not have a large effect on the development of the profile shape itself.

The use of lower efficiency factors has a clear effect on the effectiveness, as it is calculated in this study. This is coherent to the velocity of the profile evolution. However, the effect is only significant after the first six months. With the use of efficiency factors that are twice as low as the formerly used, the effectiveness six months after the dumping is about two thirds of what it was with the higher factors. But after one
and two years the effectiveness has increased equally in both situations.

7.4 CONCLUSIONS

A number of differences between the Dutch and the Gold Coast situation have to be recognized.

Although the nourishment depth may be about the same (RL-6m to RL-10m), the sand is transported shoreward much slower in the Dutch situation than it is at the Gold Coast. When the nourished bar flattens out in the Gold Coast situation, shoreward transport of the whole bar takes place at the same time. In the Dutch situation the shoreward transport takes place much slower, which causes the 'loss' of nourishment sand into deeper sections. If this is due to the shorter waves, due to the less steep average bottom slope, or a combination of both or other factors, remains to be seen from further investigations (see also Chapter 9).

The calculations of the effectiveness of the nourishment shows that the effect on the beaches (to 600m offshore) of a nearshore nourishment in front of the Dutch coast, applied beyond NAP-6m, is very low, at least in the first two years after the dumping. However, when a nourishment is applied at relatively shallow water (between NAP-2.5m and -6.5m in the calculations), the effectiveness can be much higher, even in the first year after the dumping, and most of the nourished sand is transported shoreward.
In addition to the conclusions that have been stated in the previous chapters, regarding the nourishment behaviour and the UNIBEST models, a few general conclusions can be drawn as well.

First, it is clear that a nearshore nourishment at the Gold Coast, dumped between the -6 and -10m depth contours, has, in time, an undeniable positive effect on some parts the beaches. However, further study will have to specify the quantitative aspects with regard to the economical desirability of nearshore nourishments, compared to upper beach nourishments. The author's opinion is that a combination of both would probably be the best solution. If immediate deposition of sand on the beaches is required for tourist purposes, nearshore nourishment only will probably take too long to provide a usable beach.

Second, both survey data analysis and model computations of the Gold Coast situation have shown that the transport of nourished sand in the nearshore area is indeed shoreward. It has not been found that any of the nourishment sand is lost in deeper water. This has to be proven, of course, with detailed volume computations, but at this stage it seems as if the cross-shore transport takes place in shoreward direction only.

Third, it has been found that the results of the Gold Coast nearshore nourishments should not be extrapolated to the Dutch situation without utmost care and without detailed investigations into the local circumstances. When applied at the same depth as in the Gold Coast situation, a nourishment at the Dutch nearshore will lead to some loss of sand to deeper sections, where at the Gold Coast this does not occur. Apparently, the different wave climate at the Dutch North Sea causes different cross-shore transport mechanisms.

A number of further studies can be carried out as an extension to this one. In the next chapter a few recommendations are made regarding the possibility of further investigations.
9. FURTHER STUDY

9.1 INTRODUCTION

Although this study has been finished, it does not mean that there is an end to the investigations into nearshore nourishments already. On the contrary, this study has left a lot of questions, which for lack of time, have been left unanswered. The study in this report has mainly been an investigation into the qualitative aspects of nearshore nourishments. In order to be able to make more quantitative calculations, further study will be necessary.

In this chapter a number of suggestions will be given regarding subjects for further investigations. Two main aspects are considered for further study: Regarding further survey data analyses and regarding the UNIBEST-models.

9.2 FURTHER SURVEY DATA ANALYSES

The Gold Coast monitoring program which started together with the 1988 nearshore nourishment, provides a lot of data of different kind. Some of these data have been used in this study, but the collection of data still continues. It would be very useful to keep processing these data to show the changes of the nearshore area in time, in order to be able to make predictions for future situations.

At this moment the BPA is already using the latest survey data to make bottom contour plots, but also profile plots can be very worthwhile producing, for a lot of information can be derived from a series of contour plots, as was done in this study.

More detailed quantitative volume calculations would also be of great use. This study has mainly dealt with qualitative aspects of the nearshore nourishment behaviour. Detailed volume calculations, to determine the real effectiveness of the nearshore nourishments should be carried out in order to be able to carry out an economical comparison between upper beach nourishments and nearshore nourishments. This could be of great use in the decision making when there is the choice between nearshore and upper beach nourishments.

9.3 THE UNIBEST MODELS

After the calculations with the UNIBEST models had been completed, it was obvious that, in some aspects, the model computation results differed fairly from reality.
Since a realistic time series of waves did not result in any significant differences with the computation results obtained by using an average time series (see Section 6.4), it would be useful if detailed sensitivity analyses were carried out to find out by which factors the model results are influenced. In future calculations could then be accounted for these effects, when expectations of computation results are stated.

Furthermore it would be very useful to continue the investigations into the possibility of nearshore nourishments in front of the Dutch coast. The brief study in this report has shown that the effect of nearshore nourishments on the Dutch coast will be different from the effect it has on the Gold Coast. The shoreward migration of the nourished sand seems to be much slower under Dutch circumstances. Investigations into the cause of this phenomenon and detailed sensitivity analyses will have to bring about a nearshore nourishment design that is most economical and effective.

Also the nourishment calculations should be performed for a longer period than the two years in this study. It could be of great use knowing in what way a nearshore nourishment in front of the Dutch coast behaves in, for example, a ten year period.

Finally, more investigations should be carried out into the 'life time' expectancy of a nearshore nourishment, both in the Gold Coast and in the Dutch situation. As Roelvink did in 1988 [8], predictions can be made of the expected period a nourishment will be effective on the beaches.
REFERENCES

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Gold Coast City Council
Rijkswaterstaat (Dutch Public Works)
GOLD COAST NEARSHORE NOURISHMENT STUDY
INVESTIGATION AREA

DELFt UNIVERSITY OF TECHNOLOGY

Fig. A.2
GOLD COAST NEARSHORE NOURISHMENT STUDY
LAYOUT OF SURVEY LINES

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Fig.A.4
APPENDIX B:

X1,Y1 CO-ORDINATE SYSTEM
B. X1,Y1 CO-ORDINATE SYSTEM

In order to produce decent depth contour plots and pictures of depth differences, the measurement data, discussed in Chapter 4, had to be interpolated to a regular grid of points. This grid had to cover the entire area that is considered in this study, and it also had to be easy to use in the determination of the coastal processes.

It was chosen to use the base-point of survey line Eta25.0 as the origin of the new co-ordinate system. The line Eta25.0 would also be the new Yl-axis (positive seaward). The Xl-axis was chosen to be perpendicular to the Yl-axis, with its positive direction towards Point Danger.

All survey line data points were given in the GCCC co-ordinate system (E,N co-ordinates), by means of the distance to the base point of the survey line (D) and its bearing (B). So each data point could be written as:

\[
E(i) = E(\text{base}) + \sin(B) \times D(i) \\
N(i) = N(\text{base}) + \cos(B) \times D(i)
\]

The base point of Eta25.0 (E0,N0) is (20108.09, 21348.28) and its bearing (α) is 38.8747° (= 0.6784919 rad). All data points had to be related to these values. It can be proven that a data point with the co-ordinates E(i),N(i) can be rewritten as Xl(i),Yl(i) as follows:

\[
Xl(i) = Xl'(i) \times \cos(\alpha) - Yl'(i) \times \sin(\alpha) \\
Yl(i) = Xl'(i) \times \sin(\alpha) + Yl'(i) \times \cos(\alpha)
\]

in which \(Xl'(i) = E(i) - E0\)
\(Yl'(i) = N(i) - N0\)

These results have been used to write a number of programs, called REFORM*, to transform data points from one co-ordinate system into an other. The, still irregularly divided, transformed data points could then be used to interpolate to a regular grid. This grid was generated by the program GRID. It consisted of about 180,000 points, spaced 50m in the Xl-direction and 10m in the Yl-direction, and covering an area of about 9 km² (see figure B.1).
APPENDIX C:

PROFILE PLOTS
GOLD COAST NEARSHORE NOURISHMENT STUDY
LOCATION OF SURVEY LINES
scale 1 : 30000
D.U.T. | Fig.C.1
GOLD COAST NEARSHORE NOURISHMENT STUDY
PROFILE PLOT SURVEY LINE K1.0

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Fig.C.2
GOLD COAST NEARSHORE NOURISHMENT STUDY
PROFILE PLOT SURVEY LINE K6.0

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Fig.C.3
GOLD COAST NEARSHORE NOURISHMENT STUDY
PROFILE PLOT SURVEY LINE K21.0
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Fig. C.6
GOLD COAST NEARSHORE NOURISHMENT STUDY
PROFILE PLOT SURVEY LINE K28.0
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Fig.C.8
GOLD COAST NEARSHORE NOURISHMENT STUDY
PROFILE PLOT SURVEY LINE K36.0
distorted scale
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Fig.C.10
SURVEY LINE: ETA22.0

BASE: 21047.78 E / 20590.75 N

BEARING OF LINE: 38deg52'29"

LEGEND:  

11/87
11/88
07/89
01/90

DISTANCE FROM BASE (m)
APPENDIX D:
DIFFERENCE PLOTS
ORIGIN OF THE X1-Y1 AXES: 28108.89 E / 21346.28 N
(BASE POINT OF ETA 25.0)
ANGLE BETWEEN X1-AXIS AND E-DIRECTION: 38 deg 52' 29'' (clockwise)

TWEED RIVER REVIEW PHASE IIa STUDY
DELFT HYDRAULICS

scale 1 : 30000
FIG. D.1.

H 0085

0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000

-600 -200 0 200 400 600

X1 (m)

TUGUA SOUTH
BILINGA NORTH
KIRRA NORTH
BILINGA SOUTH
KIRRA CENTRAL
KIRRA EAST
COBLANGATA
ORIGIN OF THE XI-Y1 AXES: 20108.09 E / 21348.28 N
(BASE POINT OF ETA 25.0)
ANGLE BETWEEN XI-AXIS AND E-DIRECTION: 38deg52'29'' (clockwise)
ORIGIN OF THE X1-Y1 AXES: 20100.09 E / 21348.28 N
(BASE POINT OF ETA 25.0)

ANGLE BETWEEN X1-AXIS AND E-DIRECTION: 38deg52'29'' (clockwise)
ORIGIN OF THE XI-Y1 AXES: 28198.89 E / 21348.28 N
(BASE POINT OF ETA 25.0)

ANGLE BETWEEN XI-AXIS AND E-DIRECTION: 38deg52'20'' (clockwise)
ORIGIN OF THE XI-Y1 AXES: 20199.89 E / 21349.28 N
(BASE POINT OF ETA 25.0)

ANGLE BETWEEN XI-AXIS AND E-DIRECTION: 38deg52’29’’ (clockwise)
ORIGIN OF THE XI-Y1 AXES: 201°52.89 E / 21°348.28 N
(BASE POINT OF ETA 25.0)
ANGLE BETWEEN XI-AXIS AND E-DIRECTION: 38°52'29'' (clockwise)
APPENDIX E:
DEPTH CONTOUR PLOTS
TWEED RIVER REVIEW PHASE IIa STUDY
ISO DEPTH LINE PLOT 1987
DELFT HYDRAULICS
TWEED RIVER REVIEW PHASE IIa STUDY
ISO DEPTH LINE PLOT 1188

DELFTE HYDRAULICS

scale 1 : 30000

H 0085 FIG.E.3
TWEED RIVER REVIEW PHASE IIa STUDY
ISO DEPTH LINE PLOT 0489

DELFT HYDRAULICS

scale 1 : 30000

H 0085 FIG. E.4
LEGEND: DEPTH CONTOURS A.L. +2m TO A.L. -15m
HEIGHT DIFFERENCE BETWEEN TWO LINES: 1.0m

TWEED RIVER REVIEW PHASE IIa STUDY
ISO DEPTH LINE PLOT 0190
DELFT HYDRAULICS

scale 1: 30000
H 0085 FIG. E.7
APPENDIX F:
THE ‘RANRAN’ INTERPOLATION PROGRAM
F. THE 'RANRAN' INTERPOLATION PROGRAM

The program that was used to interpolate the bottom height data to a regular grid of points, in order to make the depth contours and the difference plots, was called 'RANRAN' and has been written by J.A. Roelvink.

A schematic presentation of how the program operates is given below:

**Given:**
- A set of (random) depth data points: $X_1(i)$, $Y_1(i)$, $Z_1(i)$;
- A set of $(X_2,Y_2)$ points, generated by the grid generator 'GRID', at which interpolated depth values $(Z_2)$ must be found.

**Actions:**
- Read $X_1$, $Y_1$, $Z_1$ arrays;
- Read $X_2$, $Y_2$ arrays;
- Generate a boundary (outer envelope), using subroutine 'BOUND', outside which dummy values must be assigned to the $Z_2$ variables;
- Determine derivatives of $Z_1$ in $X_1$ and $Y_1$ direction;
- Create the four quadrants of $(X_2,Y_2)$ grid point;
- Determine closest three points in each of four quadrants and use these, together with the derivatives, for the interpolation procedure, on the condition that $X_2$ and $Y_2$ fall within the boundary;

Write $X_2$, $Y_2$ and $Z_2$ to a file.
APPENDIX G:

MATHEMATICAL-PHYSICAL DESCRIPTION OF THE UNIBEST MODELS
G. MATHEMATICAL-PHYSICAL DESCRIPTION OF THE UNIBEST MODELS

In this appendix a description is given of the formulations that are used in the model calculations. The literature that has been used for this description is listed in the list of references: [10], [11], [15].

G.1 THE LONGSHORE TRANSPORT MODEL UNIBEST-LT

In the model UNIBEST-LT is considered a uniform beach of arbitrary cross-shore profile with straight, parallel depth contours, attacked by a random wave field. In this situation it is chosen to account for the sediment transport due to the alongshore flow induced by the waves and the tide.

The wave equations

The basic equations describing the wave decay while taking account of the current refraction effect and the wave-induced cross-shore water level set-up are the wave action equation and the cross shore momentum equation:

\[
\frac{d}{dx} \left[ c \cos \alpha \frac{E}{\omega_r} \right] + \frac{D_b}{\omega_r} + \frac{D_f}{\omega_r} = 0
\]

\[
\frac{d}{dx} S_{xx} + \rho g (h_o + \eta) \frac{dn}{dx} = 0
\]

where:

\[
E = \frac{1}{8} \rho g H_{rms}^2
\]

\[
c_g = \frac{3 \omega_r^2}{4k}
\]

\[
\omega_r = \omega - k \sin \alpha, \quad \omega = 2\pi/T
\]

\[
\omega_r^2 = gk \tanh (kd)
\]

\[
D_b = \frac{1}{4} \rho g a_c Q_b (\omega_r/2\pi) H_m^2
\]

\[
D_f = \frac{1}{8} \rho f_w \pi^{-\frac{1}{2}} (\omega_r H_{rms}/\sinh (kd))^3
\]

\[
H_m = (0.88/k) \tanh (\gamma kd/0.88)
\]

\[
S_{xx} = E(n(1 + \cos^2 \alpha) - \frac{1}{2})
\]

\[
n = \frac{1}{2} kd/\sinh (2kd)
\]
The wave angle with the shore normal is after Snell's law:

\[ k \sin(\alpha) = \text{constant} \]

**The longshore current equations**

The basic equation describing the longshore current distribution in the longshore momentum equation:

\[
\frac{d}{dx} S_{yx} + \rho gd \frac{dh_0}{dy} + \rho \frac{g}{C^2} V |V_{\text{tot}}| = 0
\]

where:

\[
S_{yx} = S_{xy} = \text{En} \cos \alpha \sin \alpha
\]

\[
V_{\text{tot}} = (V^2 + U_b^2)^{\frac{1}{2}}
\]

\[
U_b = \frac{1}{2} \omega_r H_{\text{rms}} / \sinh(kd)
\]

\[
C = 18 \log (12d/k)
\]

and \(dh_0/dy\) is the alongshore tidal slope, implicitly defined by the tidal velocity \(V_{\text{tidal}}\) at the reference depth \(d_{\text{ref}}\), as follows:

\[
V_{\text{tidal}} = C \sqrt{(d_{\text{ref}} dh_0/dy)}
\]

The coefficient in these equations is the bottom roughness value \(k\), which may vary between general cm's and several dm's to yield results comparable with field measurements.

**THE SEDIMENT TRANSPORT FORMULATIONS**

The respective local transport formulations which have been included are those of Bijker, Engelund-Hansen, Van Rijn, Bailard and CERC.

The formulations of Bijker, Van Rijn and Bailard, which have been used in the model computations in this study are described concisely below.
Bijker's formula:

\[ S = S_b + S_s \quad (\text{m}^3/\text{m}/\text{s}) \]

where

- \( S_b \) = bottom sediment transport and
- \( S_s \) = suspended sediment transport

The formulation of \( S_b \) reads:

\[ S_b = b \frac{D_{50}}{C} \frac{V}{e} \exp \left( -\frac{0.27 \Delta D_{50} C^2}{U_b V^2} \right) \]

in which the mean flow is represented by \( V \) and the wave effect by \( U_b \), which were defined earlier on.

The sediment and bottom characteristics are:

- \( D_{50} \) = median (50\%) grain diameter
- \( D_{90} \) = 90\% grain diameter
- \( \Delta \) = relative density
- \( r_c \) = bottom roughness (= 0.5-1.0 times ripple height)
- \( \rho_s \) = sediment's density
- \( \omega \) = sediment's fall velocity

From these parameters the following bottom parameters are derived:

- \( C \) = Chezy coefficient = 18 \log(12d/r_c)
- \( C_{90} \) = 18 \log(12d/D_{90})
- \( \omega = (C/C_{90})^{1/2} \)
- \( f_w = \exp \left[-6.0 + 5.2 \left(\frac{U_b}{\omega r_c} \right)^{-0.2}\right] \)
- \( \xi = C \left(f_w/2g \right)^{1/2} \)

The coefficient is \( b \) which ranges from 1 to 5 with the former advised for use outside the surfzone and the latter for use inside the surfzone.

The formulation for \( S_s \) (\text{m}^3/\text{m}/\text{s}) reads:

\[ S_s = 1.83 S_b \left[I_1 \ln(33d/r_c) + I_2\right] \]
where:

\[ I_1 = R \int_{r_c/d}^{1} \left( \frac{(1-y)}{y} \right)^{z_w} dy \]

\[ I_2 = R \int_{r_c/d}^{1} \ln y \left( \frac{(1-y)}{y} \right)^{z_w} dy \]

\[ R = \frac{2.16 (r_c/d)^{2z_w-1}}{(1 - r_c/d)^{2z_w}} \]

\[ z_w = \frac{W}{(\kappa V_w)} \quad (\kappa = 0.4) \]

\[ V_w = \frac{1}{2} \frac{V}{C} \left[ 1 + \frac{1}{2} \left( \frac{U_b}{V} \right)^2 \right] \]

**Formula of Van Rijn:**

The total transport consists of a bottom transport and a suspended transport:

\[ S = S_b + S_s \] (m³/m/s)

The bottom transport is given as:

\[ S_b = a V_b c_a \]

where:

- \( a \) = bottom transport layer thickness

\[ V_b = \frac{1}{\kappa} \left[ -1 + \ln \left( \frac{30a}{r_c} \right) \right] V_{w,c} \]

\[ c_a = 0.015(a) \left( \frac{D_{50}}{a} \right)^{1.5} \left( \frac{D_{90}}{a} \right)^{0.3} \]

\[ V_{w,c} = \left( \frac{1}{8} \frac{f_c}{r_c} \right)^{1/3} V \]

\[ D_w = D_{50} \left( \frac{D_{90}}{v_2} \right)^{1/3} \]

\[ T = \frac{T_{b,cw} - T_{b,cr}}{T_{b,cr}} \]

\[ T_{b,cw} = V_c T_{b,c} + V_w T_{b,w} = \]

\[ = \left[ \log \left( \frac{12d}{r_c} \right) / \log \left( \frac{12d}{3D_{90}} \right) \right] 0.1 \rho_f V^2 + \left( \frac{0.8}{D_w} \right) 0.1 \rho_f U_b^2 \]

\[ T_{b,cr} = \text{fct} \left[ D_w, \Delta, g, D_{50} \right] \]

in which the mean flow is represented by \( V \) and the wave effect by \( U_b \), defined earlier on.
The sediment and bottom characteristics are:

$D_{50} = 50\%$ grain diameter  
$D_{90} = 90\%$ grain diameter  
$\Delta = \text{relative density}$  
$r_c = \text{current related bottom roughness} (= 0.5-1 \text{ times ripple height})$  
$r_w = \text{wave related bottom roughness} (2-3 \text{ times ripple height})$

From these parameters the following bottom parameters are derived:

$n_c = 0.24 \left( \log(12/r_c) \right)^{-2}$

$w = \exp \left[ -6.0 + 5.2 \left( U_b/w \right)^{-0.2} \right]$, with $w \leq 0.3$

The suspended transport is given as:

$S_s = (F_c + F_w) V d c_w$

where $F_c$ and $F_w$ are correction factors for currents and waves, respectively:

$F_c = [(a/d)^{2c} - (a/d)^{1.2}]/[(1-a/d)^{2c}(1.2-z_c)]$

$F_w = [(a/d)^{2w} - (a/d)^{1.2}]/[(1-a/d)^{2w}(1.2-z_w)]$

with:

$z_c = W/(\kappa u_w,c)$

$z_w = 50 (U_b/w)^{-0.8} (H_S/d)^{0.1} (U_b/V)^{0.1} (D_w)^{-0.7}$

**Formula of Bailard:**

The transport vector due to the combined actions of steady current, wave orbital motion and bottom slope effect is calculated with the Bailard transport model in two horizontal dimensions:

$q_x = \frac{c_f}{\Delta \gamma N \tan \phi} \left[ \langle |\vec{\nu}|^2 \rangle_{x} - \frac{\tan \phi}{\tan \phi} \langle |\vec{\nu}|^3 \rangle \right] +$

$+ \frac{c_f}{\Delta \gamma N \omega} \left[ \langle |\vec{\nu}|^3 \rangle_{x} - \frac{\omega}{\omega} \tan \phi \langle |\vec{\nu}|^4 \rangle \right]$
\[
\tilde{q}_y = \frac{c_f}{\Delta g N} \tan \phi \left[ \langle |\tilde{u}|^2 \tilde{u}_y^2 \rangle - \frac{\tan \phi}{\tan \phi} \langle |\tilde{u}|^3 \rangle \right] + \\
+ \frac{c_f}{\Delta g N} \frac{\varepsilon_s}{w} \left[ \langle |\tilde{u}|^2 \tilde{u}_y^2 \rangle - \frac{\varepsilon_s}{w} \tan \phi \langle |\tilde{u}|^3 \rangle \right]
\]

where:

- \( x, y \): two directions perpendicular to each other
- \( \tilde{q}_x, \tilde{q}_y \): transport \([m^3/m'/s]\)
- \( \tilde{u} \): instantaneous, total velocity vector near the bottom \([m/s]\)
- \( \tilde{u}_x, \tilde{u}_y \): instantaneous velocity component in \( x \) and \( y \) direction respectively \([m/s]\)
- \( \tan \phi \): angle of internal friction \([\text{rad}]\)
- \( \Delta z_b \): relative density of sediment \([-]\)
- \( a_m \): acceleration of gravity \([m/s^2]\)
- \( N \): ratio of sediment volume to total volume, bed material \([-]\)
- \( \tan \phi \): angle of internal friction \([\text{rad}]\)
- \( w \): fall velocity \([m/s]\)
- \( c_f \): friction coefficient \(= \frac{1}{2} f_w \)
- \( \varepsilon_B \): efficiency factor bottom transport
- \( \varepsilon_s \): efficiency factor suspended transport
- \( f_w \): \( \exp [-5.977 + 5.213 \left( \frac{a_b}{r} \right)^{-1.194}] \)
- \( a_b \): amplitude of hor. orbital excursion \([m]\)
- \( r \): \( 2.5 \times D_{50} \)

The <> indicate averaging over time.

The longshore transport is defined as the component of the total transport vector in longshore direction.

The terms \( \langle |u|^m \tilde{u}^n \rangle \), with \( m = 2, 3, 5 \) and \( n = 0, 1 \) and \( i = x, y \), can be approximated by a Taylor series containing separate terms for the wave orbital motion and the steady current, as well as the angle between waves and currents.

Two Taylor expansions are possible: one with the orbital motion small compared to the steady current and vice versa. A smooth transition from one formulation to the other is taken care of.

The wave orbital motion is calculated using a high order stream function method. In order to reduce computing time the required characteristics of the orbital motion are tabulated in dimensionless form as a function of wave height and wave period,
both made dimensionless with water depth and acceleration of gravity.

The steady current velocity is taken at a fixed reference level of 0.20 m; it is calculated from the depth-averaged velocity using a logarithmic velocity profile with roughness of 2.5 times $D_{50}$.

The weighting procedure

The integrated transports are determined using a weighting procedure, accounting for wave induced longshore flows and tide induced longshore flows.

Each calculation uses as boundary conditions a combination of a set variables from the list of wave data (list 1) and a set from the list of tide data (list 2). So the transport can be expressed symbolically as: $S = S(v1,v2)$.

The integrated transport $SI$ is defined as:

$$SI = \frac{1}{n1} \sum_{i=1}^{n1} g1(i) \times 3600 \times 24 \frac{1}{n2} \sum_{j=1}^{n2} g2(j) / 100 \times S(v1(i),v2(j)) \times 10^{-6} \text{ (mega m}^3)$$

where $g1(i)$ is the weight of set 1, combination $i$, in days $g2(j)$ is the weight of set 2, combination $j$, in %

$$G1 = \frac{1}{n1} \sum_{i=1}^{n1} g1(i) \text{ must be } \leq 365 \quad G2 = \frac{1}{n2} \sum_{j=1}^{n2} g2(j) \text{ must be 100}$$

The average transports in (m$^3$/s) is the average over $G1$ days.
UNIBEST-TC is a Time-dependent Coastal profile model, which computes the development in time of an arbitrary beach profile along an otherwise uniform coast. The sediment transport is primarily due to cross-shore phenomena induced by a random wave field. A small gradient in wave- and/or tide-induced longshore current may be a secondary source.

The computational algorithm is implicit, so that there is mutual interaction between the components of the model (see Figure G.1).

The formulations of the model components are described concisely below:

The wave equations

* A one-dimensional wave propagation description for a linear random wave field of invariable frequency with dissipation due to breaking and bottom friction

* The wave equations, used to describe the wave decay while taking account of the current refraction effect and the wave-induced cross-shore water level set-up (the wave action equation and the cross-shore momentum equation)

The wave equations have been described in Appendix G.1.

The current equations

* The basic equations describing the longshore current distribution, accounting for a tidal velocity (as described in Appendix G.1)

* A simplified, analytical description of the semi-analytical description of the net wave-induced cross-shore current, the undertow, in the vertical plane (Stive and Wind, 1986)

* A semi-analytical description of the asymmetrical variation of the near-bottom orbital velocity (Stive, 1985)

The wave orbital motion is calculated using a high order stream function method. In order to reduce computing time the required characteristics of the orbital motion are tabulated in dimensionless form as a function of wave height and wave period, both made dimensionless with water depth and acceleration of gravity.

The Bailard transport model

Cross-shore transport mechanisms are induced by a variety of cross-shore flows, such as asymmetric oscillatory flow, wave grouping-induced long-wave flow, breaking-induced turbulent flow
and momentum decay-induced undertow.

The cross-shore transport formulation that is used is the one of Bailard (1981). Bailard based his formulation on the theory of energy dissipation by Bagnold (1966), which states that sediment transport is related to energy dissipation and that some of the energy in a current is used to move sediment grains or to keep them in suspension. Bailard adapted the theory of Bagnold to the influence of waves and to the influence of the beach slope.

The transport vector which is calculated with the Bailard transport model in two horizontal dimensions, is described in Appendix G.1 as the formula of Bailard.

In the formulation a distinction is made between bed load transport in a granular-fluid shear layer, and suspended load transport in a layer of greater thickness, typically in the order of several centimeters. The instantaneous total load transport is therefore given by:

$$ S(t) = S_b(t) + S_s(t) $$

Energy dissipation can be described by the product of a force (the shear stress, which is proportional to the square of the velocity) and the distance over which it is applied (which can be described by the velocity as well). Therefore the energy dissipation is a function of the instantaneous velocity $u(t)$.

The cross-shore transport formulations of Bailard for suspended and bed load, derived from the two-dimensional model, are:

$$ S_b(t) = \frac{1}{2} \frac{\rho \ c_f \ \epsilon_b}{(\rho_s - \rho)g \ (1 - p) \tan \varphi} \left[ |u(t)|^2 u(t) - \frac{\tan \beta}{\tan \varphi} |u(t)|^3 \right] $$

$$ S_s(t) = \frac{1}{2} \frac{\rho \ c_f \ \epsilon_s}{(\rho_s - \rho)g \ (1 - p) \ w} \left[ |u(t)|^3 u(t) - \frac{\epsilon_s}{w} \ tan \beta \ |u(t)|^4 \right] $$

where

- $S_b$ : cross-shore immersed weight bed load transport rate
- $S_s$ : cross-shore immersed weight suspended load transport rate
- $u(t)$ : instantaneous velocity near the bottom
- $\rho$ : mass density of water
- $\rho_s$ : mass density of sediment
- $c_f$ : drag coefficient of the bed (related to $f_w$)
- $\varphi$ : angle of internal friction
- $w$ : fall velocity
- $\beta$ : beach slope
- $\epsilon_b$ : efficiency factor (0.10), bed load
- $\epsilon_s$ : efficiency factor (0.02), suspended load

Because only a part of the dissipated energy is used for sediment transport, efficiency factors are used to relate the transport to the energy dissipated.
The terms $<|u(t)|^n u(t)^n>$, can be approximated by a Taylor series containing separate terms for the wave orbital motion and the steady current, as well as the angle between waves and currents. (See e.g. Roelvink and Stive, 1989 [13].) Two Taylor expansions are possible: one with the orbital motion small compared to the steady current and vice versa. In the program a smooth transition from one formulation to the other is taken care of.

Profile development

The model is able to account for bottom level variations in the cross-shore transport calculations. The bottom level computation is based on sediment conservation.

The following aggregate flow chart illustrates the concept of the computation procedure for the purely cross-shore case:

![Flow chart UNIBEST-TC computation procedure](image-url)

Figure G.1 Flow chart UNIBEST-TC computation procedure
APPENDIX H:
LONGSHORE TRANSPORT PLOTS
Longshore transport along the coast
DATE: SEPTEMBER 1987

Longshore transport along the coast
DATE: NOVEMBER 1988
Longshore transport along the coast

DATE: JULY 1989

GOLD COAST NEARSHORE NOURISHMENT STUDY
CALCULATED LONGSHORE TRANSPORT
DELFT UNIVERSITY OF TECHNOLOGY

Fig.H.2
APPENDIX I:
CROSS-SHORE DEVELOPMENT PLOTS
LEGEND: ______________ ii/88 profile (measured)  
______________ calculated profile  
______________ measured profile

GOLD COAST NEARSHORE NOURISHMENT STUDY
K1.0 (TUGUN WAVES)
DELFT UNIVERSITY OF TECHNOLOGY

07-'89
01-'90

Fig.I.1
LEGEND: 
- 11/89 profile (measured) 
- calculated profile 
- measured profile 

GOLD COAST NEARSHORE NOURISHMENT STUDY 
K6.0 (TUGUN WAVES) 
distorted scale 
DELFT UNIVERSITY OF TECHNOLOGY 

Fig.I.2
GOLD COAST NEARSHORE NOURISHMENT STUDY
K16.0 (TUGUN WAVES)

DELFT UNIVERSITY OF TECHNOLOGY

Fig. I.3
LEGEND:  
- - - - - 11/88 profile (measured)  
- - - - - calculated profile  
- - - - - measured profile  

GOLD COAST NEARSHORE NOURISHMENT STUDY  
K21.0 (TUGUN WAVES)  
DELFT UNIVERSITY OF TECHNOLOGY  

Distorted scale  
Fig.I.4
GOLD COAST NEARSHORE NOURISHMENT STUDY
K24.0 (TUGUN WAVES)
DELFT UNIVERSITY OF TECHNOLOGY
Distorted scale

Fig. I.5
DISTANCE FROM BASE (m)

LEGEND:  
- 11/88 profile (measured)  
- calculated profile  
- measured profile

GOLD COAST NEARSHORE NOURISHMENT STUDY  
K28.0 (TUGUN WAVES)

DELFT UNIVERSITY OF TECHNOLOGY

Fig.I.6
LEGEND:

--- 11/88 profile (measured)

------ calculated profile

---------- measured profile

GOLD COAST NEARSHORE NOURISHMENT STUDY

ETA22.0 (TUGUN WAVES)

distorted scale

DELFt UNIVERSITY OF TECHNOLOGY

Fig.I.7
GOLD COAST NEARSHORE NOURISHMENT STUDY
SURVEYS VS. CALCULATIONS: K1.0
DELFT UNIVERSITY OF TECHNOLOGY

FIG. 1.8
GOLD COAST NEARSHORE NOURISHMENT STUDY
SURVEYS VS. CALCULATIONS: K6.0
DELFT UNIVERSITY OF TECHNOLOGY

LEGEND: ---- 11/88 profile (measured) ---- calculated profile --- measured profile
LEGEND: 
- - - 11/88 profile (measured) 
- - - - - calculated profile 
- - - - - - measured profile

GOLD COAST NEARSHORE NOURISHMENT STUDY
SURVEYS VS. CALCULATIONS: K16.0

DELFT UNIVERSITY OF TECHNOLOGY

FIG. I.10
LEGEND: 11/88 profile (measured) --- calculated profile ---- measured profile

GOLD COAST NEARSHORE NOURISHMENT STUDY
SURVEYS VS. CALCULATIONS: K21.0
DELFT UNIVERSITY OF TECHNOLOGY
GOLD COAST NEARSHORE NOURISHMENT STUDY
SURVEYS VS. CALCULATIONS: K24.0
DELFT UNIVERSITY OF TECHNOLOGY

FIG. 1.12
LEGEND:  
- 1/18 profile (measured)  
- - - calculated profile  
- - measured profile

GOLD COAST NEARSHORE NOURISHMENT STUDY  
SURVEYS VS. CALCULATIONS: K28.0  
distorted scales  
DELFT UNIVERSITY OF TECHNOLOGY  
FIG. I.13
APPENDIX J:

VOLUME CALCULATIONS
(EROSION/ACCRETION)
GOLD COAST NEARSHORE NOURISHMENT STUDY
WAVE ATTACK SITUATIONS
DELFT UNIVERSITY OF TECHNOLOGY

Fig. J.1
GOLD COAST NEARSHORE NOURISHMENT STUDY
VOLUME CHANGES 11/88 TO 04/89

DELFT UNIVERSITY OF TECHNOLOGY

Fig. J. 2
Erosion/accretion per coastal section

CHANGES FROM 04-'89 TO 07-'89

Relative longshore transport rates

AVERAGE VALUES FROM 04-'89 TO 07-'89

GOLD COAST NEARSHORE NOURISHMENT STUDY
VOLUME CHANGES 04/89 TO 07/89
DELFT UNIVERSITY OF TECHNOLOGY

Fig.J.3
Gold Coast Nearshore Nourishment Study
Volume changes 07/89 to 11/89
Delft University of Technology

Fig J.4
Erosion/accretion per coastal section

Changes from 11-'89 to 01-'90

Fig. J.5

Gold Coast Nearshore Nourishment Study
Volume Changes 11/89 to 01/90

Delft University of Technology
APPENDIX K:
EGMOND NEARSHORE NOURISHMENT
LOCATION 1
(-12m/-8m)

LOCATION 2
(-10m/-6m)

LOCATION 3
(-6.5m/-2.5m)

EGMOND NEARSHORE NOURISHMENT STUDY
NOURISHMENT LOCATIONS

DELFT UNIVERSITY OF TECHNOLOGY

Fig.K.1
EGMOND NEARSHORE NOURISHMENT STUDY
RESULTS LOCATION 1
DELFT UNIVERSITY OF TECHNOLOGY

Fig. K.3
Fig. K.4: EGMOND NEARSHORE NOURISHMENT STUDY RESULTS LOCATION 2

LEGEND:
- --- initial profile
- --- after 5 months
- --- after 1 year
- --- after 2 years

Distance to -20m contour (m)
EGMOND NEARSHORE NOURISHMENT STUDY
RESULTS LOCATION 3
distorted scale
DELFT UNIVERSITY OF TECHNOLOGY

Fig.K.5
LEGEND:

- initial profile
- after 6 months
- after 1 year
- after 2 years

EGMOND NEARSHORE NOURISHMENT STUDY
LOCATION 2 (lower eff. factors) distorted scale
DELFT UNIVERSITY OF TECHNOLOGY

Fig. K.7

Bottom height (m+NAP)

Distance to -20m contour (m)
APPENDIX L:
SENSITIVITY STUDY RESULTS
SENSITIVITY ANALYSIS (BOTTOM SLOPE)
(WITHOUT NOURISHMENT)

LONGSHORE TRANSPORT (MJ per year)
(Thousands)


Fig.L.1

GOLD COAST NEARSHORE NOURISHMENT STUDY
SENSITIVITY STUDY (BOTTOM SLOPE)
DELFT UNIVERSITY OF TECHNOLOGY

BUIKER  +  VAN RIJN  BAILLARD
APPENDIX M:

TUGUN WAVE CLIMATE
AT -15m DEPTH CONTOUR
M. TUGUN WAVE CLIMATE AT - 5M DEPTH CONTOUR

In the model calculations one of the sets of wave data used was the Tugun directional wave climate (1981). This climate was one of the results from the refraction calculations by Delft Hydraulics in 1990 [see 9]. However, the waves were given at the -10m depth contour near Tugun. In the model computations the waves at -15m were needed, assuming that no morphological changes occur beyond that depth.

The directional wave climate near Tugun at -10m is given in Table M.1 (the directions are the angle of wave incidence to the Tugun shore normal):

<table>
<thead>
<tr>
<th>$T_p$ (s)</th>
<th>$H_s$ (m)</th>
<th>dir (deg)</th>
<th>days/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>1.00</td>
<td>-30.40</td>
<td>11.32</td>
</tr>
<tr>
<td></td>
<td>1.01</td>
<td>-4.90</td>
<td>2.11</td>
</tr>
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<td></td>
<td>1.11</td>
<td>21.40</td>
<td>2.93</td>
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<tr>
<td></td>
<td>1.03</td>
<td>44.00</td>
<td>5.38</td>
</tr>
<tr>
<td></td>
<td>0.20</td>
<td>49.00</td>
<td>7.91</td>
</tr>
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<td>8</td>
<td>0.98</td>
<td>-23.00</td>
<td>17.48</td>
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<td></td>
<td>1.16</td>
<td>-2.90</td>
<td>8.63</td>
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<td></td>
<td>1.34</td>
<td>18.60</td>
<td>18.10</td>
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<tr>
<td></td>
<td>1.32</td>
<td>36.60</td>
<td>27.86</td>
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<tr>
<td></td>
<td>0.55</td>
<td>41.80</td>
<td>32.65</td>
</tr>
<tr>
<td>10</td>
<td>1.02</td>
<td>-21.00</td>
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<td>2.07</td>
<td>16.90</td>
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<td>30.60</td>
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<td>36.80</td>
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<td>0.23</td>
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<td>50.15</td>
</tr>
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<td></td>
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<tr>
<td></td>
<td>0.32</td>
<td>31.90</td>
<td>11.18</td>
</tr>
</tbody>
</table>

Table M.1 Tugun wave climate at -10m depth contour

Using the theory of energy flux conservation (see Battjes, [10]) the waves at -10m can be re-calculated to waves at -15m.

The energy flux per m$^4$ wave crest is given as:

\[
F = E c_g
\]
in which: $F = \text{energy flux per second per } m^2 \text{ wave crest}$

$E = \text{wave energy per } m^2$

$= 1/8 \rho g H^2$

in which: $\rho$ = density of water

$g = \text{acceleration of gravity}$

$H = \text{wave height}$

$c_g = \text{wave group velocity}$

Following the wave rays, the conservation of flux between two wave rays is given by:

$$F b \cos \phi = \text{constant}$$

or, going from $a$ to $b$, by:

$$1/8 \rho g H_a^2 c_{ga} b_a \cos \phi_a = 1/8 \rho g H_b^2 c_{gb} b_b \cos \phi_b$$

in which: $b_a = \text{distance between the two wave rays at } a$, measured parallel to the depth contours

$b_b = \text{idem, at } b$

$\phi_a = \text{angle of wave incidence at } a$, to the shore normal

$\phi_b = \text{idem, at } b$

Assuming that $g$, $\rho$ and $b$ are constant, this can be rewritten as:

$$H_a^2 c_{ga} \cos \phi_a = H_b^2 c_{gb} \cos \phi_b$$

or:

$$H_b = H_a \sqrt{c_{ga}/c_{gb}} \sqrt{\cos \phi_a/\cos \phi_b}$$

$$= H_a K_s K_r$$

in which: $K_s = \sqrt{c_{ga}/c_{gb}} = \text{shoaling factor}$

$K_r = \sqrt{\cos \phi_a/\cos \phi_b} = \text{refraction factor}$

The directions of the waves (the angle of incidence to the shore normal) can be determined by applying Snell's law:

$$\sin \phi_a/c_a = \sin \phi_b/c_b$$

Using the above mentioned theory for waves at the -10m and -15m depth contour, the Tugun wave climate at -15m was calculated. This climate is given in Table M.2 (which is also Table 4.1 of the report):
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Table M.2 Tugun wave climate at -15m depth contour