numerical models of today.

Also with regard to the design of the structures and the execution of the works the existing experience proved to be insufficient. The final closing-gaps were much larger and had much greater discharges then ever before. This was equally valid for the design of the discharge sluices. Therefore Thijsse was sent to participate in model investigations in Karlsruhe, where a hydraulics laboratory was already in operation at the time. This may well be regarded as the direct introduction of science in hydraulic engineering in our country. Soon after this, in 1927, the Delft Hydraulics Laboratory was established and Thijsse was put in charge.

Back to the closing-off of the Zuiderzee. Although the velocities in the closing gaps of the Zuiderzee dam were higher than they had been until then, they could be closed with basically the same technique as used before. Only the scale changed. Large cranes were used to dump large quantities of qualitatively good clay in the final gap, of which the bottom was protected against scouring by fascine mattresses with a heavy stone cover.

Another leap forward in the development of the technique was made when the dikes of Walcheren, which had been bombed in the last year of World War II, had to be repaired. In the final winter of the war the dikes of Walcheren were bombed at two places in order to silence the heavy guns of the enemy that threatened the access to Antwerp via the Westerschelde. P.Ph. Jansen (1902-1982), an experienced engineer of *Rijkswaterstaat* (the Dutch Department of Public Works), was in charge of the closing of these gaps. For this operation the engineering applied at the closure of the Zuiderzee dam was not adequate. The winter had eroded the gaps to great depth so that vast amounts of material would be required, such as heavy clay and stones. Moreover, the velocities in the gaps during the final phase of the closing would be considerably higher than at the Zuiderzee operation, due to the greater tidal ranges. Therefore Jansen now used an idea he had already thought of during the closing of the Zuiderzee dam, namely the use of big units by which the final gap could be closed practically instantly, before the velocities became too high. At the time the contractors were still rather suspicious of this method. Nevertheless they did the job and the operation was concluded successfully. The epos of this work, of the workers and of the inhabitants of the island, has been described by Anton den Doolaard in his novel *"Het Verjaagde Water"* (The water chased off).

The next event that had a large impact on the engineering knowledge on dikes was the storm surge of February 1953. This storm surge drowned 1834 people, flooded 1340 km^2 of land and more than 750,000 inhabitants were affected. It will be clear that the first concern was to repair the dikes and to reclaim the inundated land. Nevertheless, on 18 February, less than three weeks after the storm surge on 1 February, the Minister of Public Works, Water management and Traffic established the so-called Delta Committee. On 27 February 1954, the Committee published an interim report which included a proposal for the Delta Plan.

To close the gaps in the dikes resulting from the 1953 storm surge, the method used in Walcheren was further developed. The cooperation between engineers in the field and in the laboratory, which already started on Walcheren, was intensified and now also the contractors participated actively in the planning stage of the operations. Fig.9 shows the tests for the manoeuvring of the caissons in the closing gap.

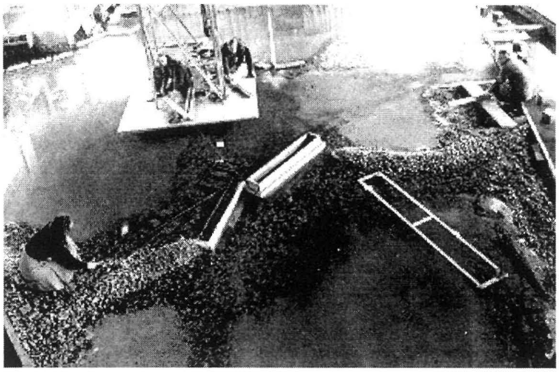

fig. 9. Manoeuvring tests.
In the Delft Hydraulics Laboratory tests for one of the closing operations with a Phoenix caisson are executed (from Dirkzwager, 1977).

When the direct damage of the 1953 storm surge had been repaired, the actual work on the Delta Plan could start. For the further design of the plan a big model of the Delta, which had already been made operational at the Delft Hydraulics Laboratory, could be used. In this model the plans of Joh. van Veen, a Rijkswaterstaat engineer, were studied. Van Veen had come up with the idea to connect the various islands in the South-West Delta of our country by dikes into groups of 3, 4, or 5 islands in order to create bigger units that could be better protected against storm surges. This plan had also been studied immediately after World War II when this same model had been set up in a large army tent. This model enabled the study of the effects of storm surges in the existing situation and in the 3, 4 and 5 islands situation. Because of these studies our engineers were at any rate not completely unprepared when the storm surge actually stroke. Fig.10 shows the rather primitive, but nevertheless reliable way in which the measurements were performed.

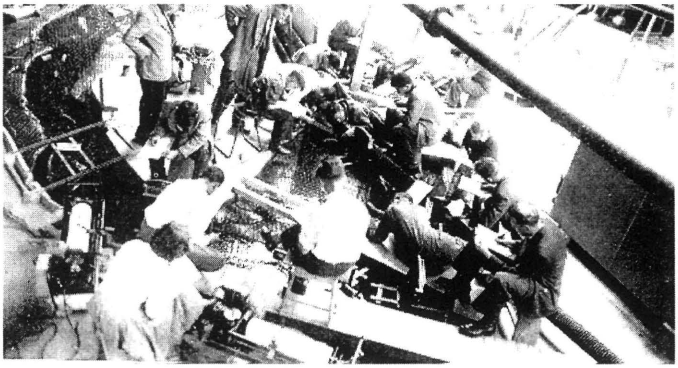

fig. 10. Tidal model of the Delta.
All measurements, just as the generation of the tides, were performed by hand and visual observations. Of course not so very accurate but rather reliable (from Dirkzwager, 1977).

It will be clear that the experiences gained during the repair of the damage of the storm surge were now used in the definite closing of the delta. Not only the method of putting big units into place was further refined, also other methods were developed. The onset of these developments is probably hidden in a remark by the engineer in charge of the closing of Schelphoek, the largest gap of 1953, made during the placing and sinking of the final caisson, a Phoenix caisson left over from the Allied landing operations on the French coast at the end of World War II: "Everything works out excellent, but every sinking operation is still an adventure and I don't like adventures." Among the other methods developed was the dumping of rock or concrete blocks of 2.5 tons by cable-way or even by helicopter.

The set-up of the sequence of the various closing operations was such that the Oosterschelde, the by far greatest branch, would be closed last. In this way all experience gained in the previous operations could be used for this final one. It was decided that the Oosterschelde would be closed by dumping concrete blocks by cable-way. This method was applied successfully for the closure of the Grevelingen and the Brouwerhavense Gat.

Then, however, something unforseen happened, although it had been "in the air" for some time. The method of "repressive tolerance" might work to fight the sea, it did not work with regard to the Dutch population. They became increasingly aware of the ecological value of the Oosterschelde as a large and relatively clean salt water tidal basin. They realized that the planned fresh water basin would suffer a lot from the inflow of highly polluted water from the great rivers. Moreover the creation of a fresh water basin for agricultural purposes was no longer essential because of the already existing overproduction of agricultural products. In combination with the desire to save the Oosterschelde on behalf of the oyster and mussel culture, this resulted in a strong social movement that pleaded for consideration of the possibilities to maintain the salt tidal environment. Two options existed. The most drastic option was not to close the Oosterschelde at all, but to only heighten the dikes. This solution was not very popular with the engineers of Rijkswaterstaat and the majority of the population of Zeeland. Another less radical but much more sophisticated solution was to create a storm surge barrage that would allow for a sufficiently large tidal movement into the Oosterschelde, but which would prevent storm surges from entering. The inevitable committee was established (Committee Klaasesz) in August 1973 and in March 1974 they came up with an interesting, although not very realistic solution. Their proposal comprised a porous dam which would allow a sufficient tidal movement in the Oosterschelde under normal tidal conditions. Under storm surge conditions the water levels in the Oosterschelde would be reduced to acceptably low values.

After the presentation of yet another alternative by a group of Dutch contractors, eventually a working group of Rijkswaterstaat, contractors and, last but not least, the Delft Hydraulics Laboratory, developed the eventually accepted plan. This cooperation in the design phase between contractors and engineers of Rijkswaterstaat had by now already become common practice.

Since Rijkswaterstaat realized that the experience obtained in the realization of one project should be used in the next, the so called "learning effect," the traditional practice of public tendering subsequently followed by negotiations "with the knives out" was not used for the large Delta Project. Moreover, the works were so extensive that consortia between contractors were formed to execute the jobs. So Rijkswaterstaat discussed the design and execution of the plan, including the price, with one consortium of contractors.

The final plan for the Oosterschelde comprised a number of large piles with gates that can be closed in case of a storm surge. Due to the decrease of the cross-section the tide in the Oosterschelde was reduced by some 10 percent, which was regarded sufficiently small to maintain the valuable ecological environment.

In the meantime work on the closure according to the original plan had already started. The bottom protection for the closing operation had been constructed and some of the piles for the cable-way were ready. All this had to be removed. Moreover, the engineers faced another problem. As I mentioned previously, the policy had been to lastly close the Oosterschelde, the by far largest branch, in order to be able to use the experience gained in the previous works. This was no longer possible. Now the most difficult job would have to be executed without the help of the learning effect. Although the closing of final gaps by big units was not very much in favour any longer (the dislike of adventures), now an even bigger adventure had to be undertaken: the positioning of the huge piles with equipment that had been especially developed for this purpose. This could only be done thanks to the increasingly developed technology. It is a great compliment to everybody concerned that the job was finished almost flawlessly.

Although the Delta Project was originally based almost exclusively on technical, physical and economical considerations, it also had the effect that coastal engineers realized that the Delta is not only a complex physical system, but also an ecological one. This growing awareness of ecological values was picked up quickly by the coastal engineers. In 1970 H.J. Ferguson, at the time in charge of the Delta Works, established an ecological research group within Rijkswaterstaat of which the status equalled that of the coastal engineering group within the project team of the Delta Works.

Nowadays this environmental awareness is commonly accepted all over the world and has led to the requirement to execute Environmental Impact Assessments for large projects.

In line with these large coastal structures presently the storm surge barrage in the Rotterdam Waterway is being constructed. In this case the design of the structure has been entirely made by a group of contractors after winning a competition between various consortia of contractors. Only after the contract had been awarded, Rijkswaterstaat engineers began to play an active role in the final design.

The protection of our sea dikes also has been subject for further research. J.W. van der Meer carried out research with the aim to develop design criteria for rock slopes and gravel beaches under wave attack (Van der Meer, 1988). Together with the Construction Industry Research and Information Association (CIRIA) and Rijkswaterstaat, the Centre for Civil Engineering Research and Codes (CUR) published manuals on this subject (CUR and CIRIA, 1991 and CUR and Rijkswaterstaat, 1994).

INLETS, ESTUARIES AND TIDAL RIVERS

In our country inlets, or better outlets, from rivers to the sea have always been a very important natural feature. They were and are vital for the approach to the harbours as well as a potential danger for the inland, since apart from being an entrance for ships, it was and is also an entrance for storm surges.

The struggle for the approach of Rotterdam is a good example. Due to the increasing size of the ocean-going ships the approach through the outlet of the river Maas was no longer sufficient. After some attempts to develop new approaches through the Delta, P. Caland (1827-1902), a Rijkswaterstaat engineer, developed an idea, which had originally been put forward by N.S. Cruquius (1678-1754) in 1739, to make a cut through the dunes at Hook of Holland from the Maas to the sea. Caland predicted that the thus created new river outlet would be self-flushing, and would therefore not require maintenance dredging. Although the plan was mildly criticized, in 1862 the government decided to execute it and in 1863 the work started. The new channel was finished in 1868, but proved to be not self-flushing and quite extensive shoaling occurred. In 1877 a committee was installed to find a solution and the result was that the plan for what had by now been called the Nieuwe Waterweg, was not officially accepted. However, other solutions were certainly not attractive because of the long detour the ships would have to make. Since Rotterdam still had confidence in the project and managed to make money available, the new outlet to the sea was maintained. For this maintenance dredging was essential and hopper-dredges with centrifugal pumps were introduced to our country by the English contractors who developed them. Part of the success has certainly been due to Leemans (1841-1929), who was in charge of the maintenance and dredging operations. The moral of this story is that you should not be too afraid to make mistakes. Caland's prediction was proved wrong but due to the decision based on this prediction Rotterdam was enabled to develop into a large harbour and the dredging industry in our country developed.

Of course more work had to be done in order to maintain the main port position of Rotterdam. In the "de Voorst" branch of the Delft Hydraulics Laboratory a large, open air model was built to study the approaches to the new extension of Rotterdam: Europoort. During these investigations a new development became clear. Originally most attention was paid to minimizing the maintenance dredging in the harbour entrance. This changed with the developments in the dredging equipment. Big trailing suction hopper dredges with swell compensated suction pipes, made maintenance dredging cheaper and, even more important, much more reliable. At the same time the size of the ships increased, a development which in its turn increased the manoeuvring problems. I remember Ferguson, at that time in charge of the development of Europoort, telling us, engineers of the Delft Hydraulics Laboratory studying the entrance to Europoort: "Now you concentrate on the nautical problem of how to get the ships in, the dredgers will deal with the maintenance."

Also the influence of the density currents as a result of the interaction between salt and fresh water had to be studied. To this end a large tidal model, operating with salt and fresh water was built in the Delft branch of Delft Hydraulics, as the laboratory was called by now. In this model the effect of the Coriolis force due to the rotation of the earth was reproduced by vertically rotating rods. This device, an idea of H.J. Schoemaker, was a real breakthrough compared to the models on turning tables that had been used for the reproduction of this effect until then.

Gradually numerical models began to take over from "real" hydraulic models. A first step in this development was taken by J.P. Mazure (1899-1990) in his doctoral thesis on the computation of tides and storm surges on tidal rivers. (Mazure, 1937). The elegant and solid method of Lorentz could not be used in this case since it was not possible to deal with upper-water discharge in that method. At the same time and subsequent to Mazure other researchers further developed the computation of tidal motions. Some of the ideas did not prosper, such as, for instance, the Electrical Method developed by Van Veen in 1937. This method was based on the analogy between alternating currents and tidal motion. Although these ideas may not have been suitable for further use, they definitely improved the understanding of the physics of the phenomena.

The basis for modern computational methods in coastal and estuary engineering was laid by J.J. Dronkers (1910-1973), who completed a doctoral thesis in mathematics at Leiden University in 1936. The above mentioned Van Veen recognized the importance of Dronkers' mathematical work in relation to computational hydraulics and so the first academic who lacked an engineering degree entered Rijkswaterstaat. His work was of great importance for many closing operations after the inundation of Walcheren in 1945 and the 1953 storm surge. Dronkers described his experiences in a book titled "Tidal Computations in Rivers and Coastal Waters", which is still the standard work for computational coastal engineering (Dronkers, 1964).

In 1967 one of his pupils, J.J. Leendertse, who worked in the USA for the Rand Corporation at the time, made a further important contribution to the implementation of mathematical models on the computer in his publication: "Aspects of a Computational Model for Long-Period Water Wave Propagation" (Leendertse, 1967).

Nowadays these models have developed to such an extent that it is possible to simulate density currents and silt deposits. However, with some modesty we might refer to a remark of Mazure in his thesis: "The result of a computation is never the solution to a problem. At most it is information that may lead to the solution. The value of this information must be evaluated in relation to validity and the reliability of the computational method" (Mazure, 1937).

For a good understanding of the physical phenomena, field research was also necessary. Partly this research was rather fundamental, such as the study of the transportation of silt by the rivers to the North Sea. This study was performed by adding markers to the silt, which would react differently from the silt when irradiated.

Another part of the field surveys concerned the collecting of essential information on behalf of model studies. Various rather extensive field surveys were executed, in the Netherlands as well as abroad, in order to obtain these data. These studies were performed both by

Rijkswaterstaat and by Delft Hydraulics. In this respect the development of the *Studiedienst* (Research Department) of Rijkswaterstaat should be mentioned. The former chief engineer of the Delft Hydraulics Laboratory, J.B. Schijf (1906-1987), was the driving force behind this development, which was also essential for the development of coastal engineering in our country. In this respect Schijf may well be regarded to be the "father" of modern coastal engineering in the Netherlands.

COASTAL MORPHOLOGY

As mentioned before, the engineering knowledge on how to maintain our sandy coast and dunes was mainly based on experience. However one very interesting fundamental study in the field of coastal morphology has been executed by the previously mentioned Joh.van Veen (1893-1995), entitled: *Onderzoekingen in de Hoofden in verband met de Gesteldheid van de Nederlandse Kust* (Measurements in the Straits of Dover and their relation to the Dutch Coast) (Van Veen, 1936). Since this work was published in Dutch it hardly reached the international engineering community.

With regard to the daily routine, however, we still mainly relied upon experience. Of course this experience was influenced by the more fundamental work of scientific pioneers such as Van Veen, and it was their influence that, at a later stage, enabled us to take the step towards more scientifically based hydraulic and coastal engineering.

Apart from the cut-through at Hook of Holland for the Nieuwe Waterweg, another exception to this more or less gradual development was the construction of the breakwaters at IJmuiden around 1875. They formed the outer harbour to the Noordzeekanaal, which leads to Amsterdam. These breakwaters were constructed by English contractors and it is questionable whether or not our engineers at the time studied the impact of the harbour moles on the adjacent coast.

Also the Delft Hydraulics Laboratory, established in 1927 with Thijsse as its first director, fairly soon started the study of harbours. The first harbour that was studied was the harbour of Zeebrugge in Belgium, in order to investigate the possibility to decrease the siltation in the harbour by guiding a part of the longshore tidal current through the harbour by a gap in the harbour mole. The second project was the harbour of Abidjan, Ivory Coast. In this project the inlet from the ocean into the lagoon at which Abidjan is situated was studied. Shortly after World War II the mouth of the river Volta in Volta and the harbour of Lagos in Nigeria followed. This was the start of an intensive involvement of the laboratory with coastal problems all over the world.

Some research on coastal problems had, however, already been executed before that time. In 1919 a model was built in the garden of the Directorate of the Zuiderzeewerken in Den Haag in order to study the wave uprush against the dikes. This work was performed within the framework of the State Committee Lorentz. Also the wind set-up was investigated during that period.

After the establishment of the Delft Hydraulics Laboratory, a 25 m long wind wave flume was built for the study of wind generated waves. Later this flume was lengthened to 50 m. Partly during World War II this flume was used for further tests. Also the influence of the water depth could be reproduced by changing the scales. The results of these investigations proved to correspond very well with the work of Sverdrup and Munk on the prediction of waves in connection with the landing operations at the end of World War II.

At the Hydraulics Laboratory, fundamental research became more and more important. In the discipline of coastal engineering the work on waves has been very important, as well as the work in the field of describing and measuring the nature and the model of the waves. Work was also done in order to better understand the scale effects in hydraulic models. All this basic research was much stimulated and guided by the man who would later succeed Thijsse as director of the Delft Hydraulics Laboratory, H.J. Schoemaker. Schoemaker gave the Delft Hydraulics Laboratory its scientific base. During this period an attempt was also made to eliminate the scale effects from the morphological models. This work later resulted in the development of a longshore transport formula.

In 1968 the field of coastal engineering got a more formal position at the Delft University of Technology because of the appointment of a professor in coastal engineering. Since then a close and fruitful cooperation between the University and the Delft Hydraulics Laboratory has developed. In 1973 J.A. Battjes was appointed lecturer in wave mechanics. After his appointment as professor in fluid mechanics in 1980, Battjes continued his pioneering work in this field. The two main points in Battjes's research through the years have been the incorporation of random-wave effects in wave models for application in offshore and coastal engineering and in coastal hydrodynamics (Battjes, 1968, 1974, 1975, 1979 and Battjes and Jansen, 1978).

fig. 11. Delta Flume.
In this 100m long, 5m wide and 7m deep flume, waves with a maximum height of 2.5 m can be generated. The wave generator which generates waves of any required spectrum is programmed to suppress waves wich are reflected by the tested structure.

The research by Rijkswaterstaat and the Delft Hydraulics Laboratory into coastal problems gradually intensified during the fifties, but it really boosted after the installation of the TAW, the *Technische Adviescommissie voor de Waterkeringen* (Technical Advisory Committee on Water Defences), subsequent to the 1962 flooding of Tuindorp-Oostzaan, a polder just north of Amsterdam. This committee was installed to advise, which it still does, the minister on all problems concerning water defence systems, which includes all dikes and ancillary works around polders, along canals, rivers and the coast. As expected, the dune coast was a rather important item from the very beginning. Therefore one of first study groups of the Committee concerned the "Erosion of Dunes." This study group investigated the erosion of dunes when attacked by a storm surge. The already known principle of this erosion is that the sand, eroded from the dune during the relatively short duration of the storm surge, stays in the foreshore, practically entirely within the breaker zone. The eroded sand is deposited in a so-called erosion profile and at calm weather after the storm surge it is transported back to the beach and from the beach back to the dune again. So when the volume of a dune is sufficiently large, no harm to the coast is done. A procedure to determine the erosion of dunes on the basis of this principle was formulated in the "*Leidraad voor de beoordeling van de veiligheid van duinen als waterkering*," in short the Guideline on Dune Erosion, which was issued by the TAW in 1984. The basis for this method was laid by J. van de Graaff (Van de Graaff, 1977) and further developed by P. Vellinga (Vellinga, 1986). For the development of the erosion profiles, research was executed in the 300 m long and 7 m deep Delta flume of Delft Hydraulics. Fig.11 gives an impression of this flume in operation.

Of course - since safety was concerned - a lot of rather fundamental research still had to be performed. Eventually a numerical model that runs on a PC was developed, with which the dune erosion under various circumstances could be calculated. However, this model still worked with an assumed, constant water level during the storm surge. Another defect inherent to this model was that fluctuations of the wave height and the bed level of the foreshore during the storm surge were not included. Especially the level of the foreshore is important since a low level foreshore provides more volume between the bed of the foreshore and the erosion profile. In that case more sand is required to form the erosion profile and consequently more dune erosion will occur. Therefore a time dependent model was developed by H.J. Steetzel [Steetzel, 1993], which was as such, however, not yet sufficient. Also the probability of the level and the position of the foreshore, the wave height and the water levels had to be included. So a probabilistic approach was required and applied.

At this moment the basis for the design of our coastal defence system is still that it is designed for a surge level and wave condition occurring with a by the Delta Law prescribed probability. For central Holland this probability is 1:10000. Under these conditions the defence system should not fail. This however, can never be stated with absolute certainty. A lower surge with more severe wave conditions can be moreover just as or even more dangerous. The scientifically right method is to calculate the failure probability under a range of combinations of surge level, wave condition and foreshore situation. The by this method calculated failure probability should have an acceptably low level. Roughly this probability is a factor 10 lower than the before mentioned probability of the desing level of the storm surge. This results for central Holland in a 1:100000 probability for failure of the defence system.

Other phenomena should also be taken into consideration, such as a possible gradient in the longshore transport and the effect of groynes. With regard to the latter the "multi line theory" as developed by W.T. Bakker was used (Bakker, 1968). In this way we have now been provided with a series of numerical models, running on PC's, to predict dune erosion and coastline changes caused by storm surges.

With regard to the defence of our dune coast, in 1990 our government officially decided in favour of the policy to maintain this coast as much as possible with soft measures such as sand suppletion, which is a continuation of the old adage of Vierlingh. It is called "Dynamic Maintenance," which intends to point out that the chosen strategy will not be followed at all costs, but that deviations are possible when required by the circumstances. "Intelligent Maintenance" would probably have been a better name. Annually the Dutch government makes available sixty million Dutch guilders for the execution of this policy, which is described in a report titled Dutch Coastal Policy (Rijkswaterstaat, 1990). The proceedings of the 22nd ICCE (Part IV) in 1990 include a comprehensive report on this subject.

Parallel to these developments within the framework of TAW, Rijkswaterstaat started the Coastal Genesis project, which includes the development of the Dutch coastline, the coast of the delta in the southwest and the Wadden Islands. This study is supposed to provide answers to, among other things, the question how our coast can be maintained at reasonable costs and how it will react to a possible rise of the sea level. Especially the behaviour of the inlets between the islands and the behaviour of the Waddenzee itself call for more fundamental research. This research is now concentrated with the NCK, *Nederlands Centrum voor Kustonderzoek* (Dutch Centre for Coastal Research), a combined effort of the Delft University of Technology, Utrecht University, Delft Hydraulics, Geological Survey and Rijkswaterstaat.

The most innovating aspect introduced by the Coastal Genesis project was the awareness that research has to be approached on a variety of temporal and spatial scales (Fig.12). Moreover, it was realized that these scales are coupled at the points where interactions occur between fluid forces (waves, tides, sea level rise) and bed responses (the physical structure of the bottom). To logically approach this challenge, three sub-projects were defined that distinguish geophysically in temporal and spatial scales. Within these sub-projects important progress was made both by working interdisciplinary and by combining field work, laboratory studies and mathematical-physical modelling. In this way perceptions and research techniques from the fields of engineering, geology and physical and historical geography were combined. In this way reconstructions of the coastline over periods of hundred to thousands year before present could be obtained. This resulted in a much better understanding of the behaviour of our coastline. Simultaneously the results were applied in the implementation of the new coastal defence policy. Although these insights are not completely new, they were rather hypothetical and could not be applied in the context of coastal fringe management prior to this project. A more process-based and quantitative foundation was accomplished by combining several complementary research approaches, aiming at:

- the geological evolution of the Dutch coastal system;
- the exchange processes between coast and tidal inlet systems;
- the sand redistribution along the coastal fringe and the exchange with the sea.

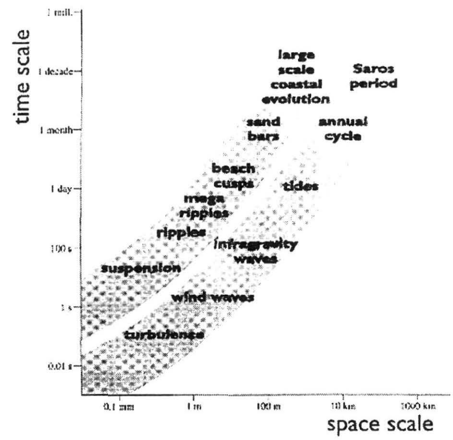

fig. 12. Time and Space Scales.
The relation between the scales in time and space of the various physical phenomena, viz. fluid motion and bed respons along a sandy coast, are shown. (from Stive and de Vriend, 1995)

This work is summarized in three reports about the Morphodynamics of the Netherlands coast on various temporal and spatial scales. (Beets et al, 1992), (Van Rijn, 1994) and (Ribberink and De Vriend, 1994). Of course this work could not have been realized without analysis of the field surveys that have been executed along the Dutch coast (Wijnberg and Terwindt, 1995). It should once more be stated that the Dutch coast is one of the best and longest observed coasts in the world. We have a 100 year long observation of HW and LW lines and a 25 year long observation of the foreshore, beach and dune profiles.

Important lessons were derived from the Coastal Genesis project. Among them is the lesson that the Dutch coast is subject to a structural sand deficit, caused by losses due to dune formation and sea level rise. On the one hand the sand supply from the rivers has decreased after the Roman era, and on the other hand there is a decreased sediment supply from the shelf and shore face towards the coast after the period of younger dune formation. Also a significant movement of sand masses within the coastal fringe has occurred, due to both natural processes and human impact.

In order to be able to understand all this, research was performed on the movement of sand in the boundary layer under influence of waves and currents in the oscillating water tunnel of Delft Hydraulics (Ribberinik and Al-Salem, 1994). In combination with the knowledge on cross-shore currents (Roelvink and Stive, 1989) this made it possible to *model the shore face profile evolution* (Stive and De Vriend, 1995).

Presently the lessons from the Coastal Genesis project are used in the context of coastal management. They lead to a more sustainable approach of the solution for the erosion problems of the coast and towards substantial savings in maintenance budgets, among other things by better design and location of nourishments and structures.
Coastal Genesis has taught us that local changes in coastline positions have consequences for the coastal evolution on larger scales and longer terms. This coherence in the coastal system is an important aspect in the evaluation of plans for a substantial extension of the coastal zone in the North Sea.

In the defence against the sea the concern about the environment has also awakened. Although safety is still the primary issue, we now realize that we can probably fulfil the safety requirements and at the same time maintain and protect the precious environment of the dune coast. Within the study group "Dune Erosion," now renamed "Sandy Coast" - and in this case there *is* something in a name - ecologists play an active role. Our knowledge of the behaviour of the coast has increased to such an extent that we can give nature a well balanced position in our coastal defence policy. In many cases we can even include natural aspects in the actual defence system. Of course this calls for further research in the field of the ecology of the dunes. Currently this research is performed within the frame work of the study group "Sandy Coast."

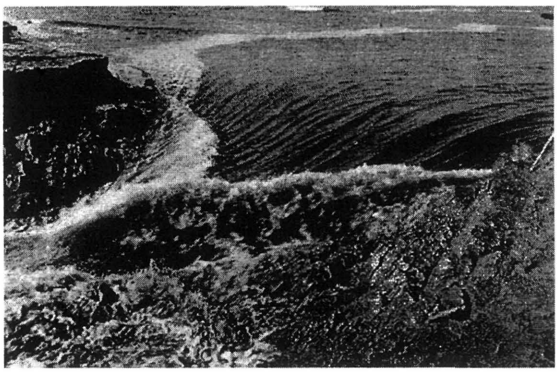

fig. 13. Breach in a sand dike.
The picture shows the breach in a sand dike some 10 minutes after the rupture. This test was executed in the fall of 1994 in the "Zwin" an inlet at the North Sea coast at the frontier between Belgium and the Netherlands (from Somers, Meetverslag Zwin proeven, 1995).

Today much of the research is performed by mathematical-physical models. However, sometimes it is still necessary to execute model tests or even full-scale tests. An example is the research performed by the Delft University of Technology and Delft Hydraulics into the development in time of dike breaches. Without further research it was not possible to model the sand transportation by the very high currents in the gap. To investigate this a breach was forced in a sand dike in the Zwin, a tidal gully at the frontier between Belgium and the Netherlands. The development in time of the width and depth of the gap was measured. Fig.13 shows the execution of the test. These full-scale tests were combined with two and three dimensional model tests. The ultimate goal was to develop a model which would be able to predict the development of a breach in a dike, in size as well as in time. This knowledge is required for the development of inundation models for polders.

At this moment research has started into the question whether it is possible to combine "hard" measures such as, for instance, offshore breakwaters, with sand suppleti-