Coastline management with GIS in the Netherlands

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ABSTRACT

254 km length of the Dutch coast consists of dunes. The actual coastline changes by erosion and accretion. Since 1990 the Dutch policy of preserving the coastline at a fixed position, by sand nourishments, is supported by GIS-applications. The applications for producing the coastline charts, and the "shoreline management tool" will be described in this paper.

The Dutch Coast

The coastline of the Netherlands is approximately. 350 km long; 254 km consist of dunes, 34 km of sea dikes, 38 km of beach flats and 27 km of boulevards, beach walls and the like. The width of the coastal dunes varies between less than 200 metres and more than 5 km **(Fig. 1 to 4)**.

The dune coast is by nature very dynamic in character. At some locations there is sand accretion, while at other locations erosion prevails. Erosion and accretion patterns also vary in time. Since the middle of the 19th century the position of the dunefoot and the high and lowwater lines have been measured every year. For this purpose fixed reference poles, beach posts, have been set up on the beach at intervals of 200 to 250 metres. Since the middle of the 1960's the annual coastline measurements are performed through a combination of remote sensing (in land) and sounding techniques (offshore). At every beach post a coastal profile is measured, extending from approximately. 200 metres landward of the beach post to approximately. 800 metres seaward. The result of this annual coastal monitoring is a unique data-set available for all types of coastal research and evaluation.

A typical example of the application of the monitoring data is the sand balance of the Dutch coastal system. On large spatial and temporal scales, the following patterns can be discerned (Stive et al., 1990):

1. In the North there is a structural loss of sand to the Wadden Sea, several stretches of the North Sea beaches are eroding;

2. On the central part of the coastline (the "stretched" Holland coast), sand is being transported from the deeper part of the foreshore to the shallower part, resulting in a steepening of the foreshore;

3. In the Delta area in the Southwest, sand is deposited in front of the closure dams. As a result of shifting gullies close to the coast, many beaches in the southwest of the Netherlands are subject to erosion;

4. Sand loss from the foredune to the inner-dunes (due to aeolian activity) are very limited.

Comparable sand balance studies have also been performed on different time and space scales. Based on that information, shoreline predictions are made, indicating locations where accretion and erosion can be expected in the coming decades.

Dynamic Preservation

In the 1980's the need for a national policy on coastal protection became more and more evident. At that time an ad-hoc policy was followed: measures were only taken when the safety of the polderland was at stake or when special values in the dune area (e.g. drinking water supply areas, nature reserves) were threatened. After the 1953 floods, which caused more than 1800 casualties, the dikes and dunes along the North Sea were strengthened to meet the required safety level, thereby ensuring the safety of the polders. If no measures are taken against ongoing coastal

Figure 1 - Typical dune coast, south of The Hague

Figure 3 - Entrance of De Slufter on Texel island

Figure 2 - Beach flat, western extreme of Vlieland island

Figure 4 - The hondsbossche Seadyke in North-Holland

erosion, however, tens of kilometres of coast will become unsafe in the near future and hundreds of hectares of valuable dune area will be lost every decade. An accelerated rise in sea level will enhance this problem even further.

In November 1990, the national Parliament decided on a new national policy for coastal protection: preservation of the coastline of 1990 (Ministry of Transport, Public Works & Water Management, 1990). This policy choice is primarily aimed at enduring safety against flooding and sustainable preservation of the values and interests in the dunes and on the beaches. To emphasise the wish for the preservation of the natural dynamics and character of the dune coast, the chosen alternative was specified and called "Dynamic Preservation".

The policy choice in 1990 marks a new era in coastal defence policy in the Netherlands. The most important aspect of this choice is that for the first time in history the Netherlands' seaward boundary is maintained at a fixed position (Hillen & De Haan, 1993). Until 1991, large sections of the Dutch coast were eroding, at some locations resulting in a retreat of 5 kilometres in four centuries. From 1990 onward all structural erosion is counteracted, thereby creating a basic provision for other functional uses in the coastal area (e.g. housing, recreation, drinking water supply and nature). Another important aspect of the policy choice was the choice for sand nourishment as the main method to combat erosion.

Coastline Charts

The new policy of "Dynamic Preservation" requires that the 1990-coastline for the entire dunecoast must be determined. For this purpose, the concept of the "basal coastline" has been developed (Hillen & De Haan, 1993). The "basal coastline" is in fact the coastline-to-be-preserved. Every year the actual position of the coastline (calculated from a series of recent coastal monitoring data) will be compared with the basal coastline to control whether the basal coastline has not been crossed. If the actual coastline is located landward of the basal coastline, corrective action is taken. In practice this means that a sand nourishment is carried out. Since 1992, a yearly assessment

is performed and nourishment works are planned according to this method. The results of the yearly assessments is presented in the "coastline charts" (Van Heuvel & Hillen, 1992).

In order to present the entire coastline on a scale of 1: 25,000, 105 charts are required, each covering an area of 4 by 4 km. The charts allow a rapid insight into the changes of the coastline position (the trend) for each section of the coast.

In 1994 the third set of charts was published. Comparison of the three sets of charts now makes it possible to determine changes in trends and the impact of local sand nourishments.

The coastline charts are produced using a Geographical Information System (GIS). A professional production program, in ARC/INFO, was made to build up the charts individually. It allows for the use of several layers of information projected onto a background. The coastline charts contain the following information:

- a satellite photo or a (scanned) topographic chart that serves as background **(Fig. 5)**.
- The most recent report is made with the topographic background, for the reason that the smallest recognisable image unit on the satellite photo is in fact a surface area of 30 by 30 metres.
- the system of monitoring sections, including their numbers, along which the annual coastal measurements are carried out. The pattern of sections and the reference line (Rijksstrandpalenlijn) was laid down in 1962.
- the trend in coastline development. This is represented in the form of bar graphs parallel to the coastline. The length of the bar indicates the extend of the trend in metres per year. A positive trend means that the coast is accreting. The bar is then drawn in a seaward direction. Conversely a bar drawn in a landward direction implies that coastal recession is taking place.
- the difference between the assessed coastline (yearly) and the basal coastline. If the difference is negative - in other words, if the assessed coastline (TKL) lies landward of the basal coastline (BKL) - the bar of the trend is red (Fig.5: dark grey or shaded). If the difference is positive, the bar is green (Fig. 5: grey or shaded with crossing lines).

The choice to use a GIS was made in 1991. At that time Rijkswaterstaat was looking for a method to (re)produce coastline charts including the results of the yearly assessment. The main problem was that yearly 105 charts have to be made within a limited time. Because only the input file of the assessment results changes every year, the production time now takes about 3 weeks including checks. In addition, the choice of using a GIS has the advantage that the data sets and coverage, which are used in this program, are available for other GIS-projects within Rijkswaterstaat.

Natural Dynamics

The dune coast of the Netherlands is of great scenic beauty and represents international biotic and abiotic values. Nature conservation organisations and ecologists fully support the policy choice of preservation of the coastline and the choice for "soft" coastal defence methods. At their request, the term "dynamic" was added to ensure the dynamic character of the Dutch coastline. Several nature conservation organisations now plead for a less strict policy with regard to the maintenance of the foredunes. Suggestions for the formation of so-called slufters and dune areas with more aeolian dynamics have been presented recently (Stichting Duinbehoud, 1992). This is well in line with the National Nature Policy Plan which identifies the coastal dunes as a part of the "ecological main structure" of the Netherlands. One of the action plans of the Nature Policy Plan is to bring the entire Dutch coastal dune area under the Nature Conservation Act.

From the viewpoint of coastal defence, there are possibilities for natural development of coastal areas, but not everywhere and not without conditions. On the beach plains at the extremes of the Wadden Islands no active coastal defences measures are carried out. The natural development of these areas is not hindered as long as the islands do not break through.

On the other hand, several dune areas (especially in the southwestern part of the country), are too narrow to allow for nature development experiments. For the remaining dune areas a less strict stabilisation policy could be considered as long as the safety of the polderland is not endangered.

One of the specific features of a dynamic sandy coastline is a "slufter": a wet dune valley which is influenced by the tides at regular intervals. At present two major slufter-systems exist on the Dutch coast: De Zwin (at the Belgian border) and De Slufter on Texel Island in the Northwest (Fig. 3). Along the coast of central Holland, several locations have been mentioned as possible sites for slufter

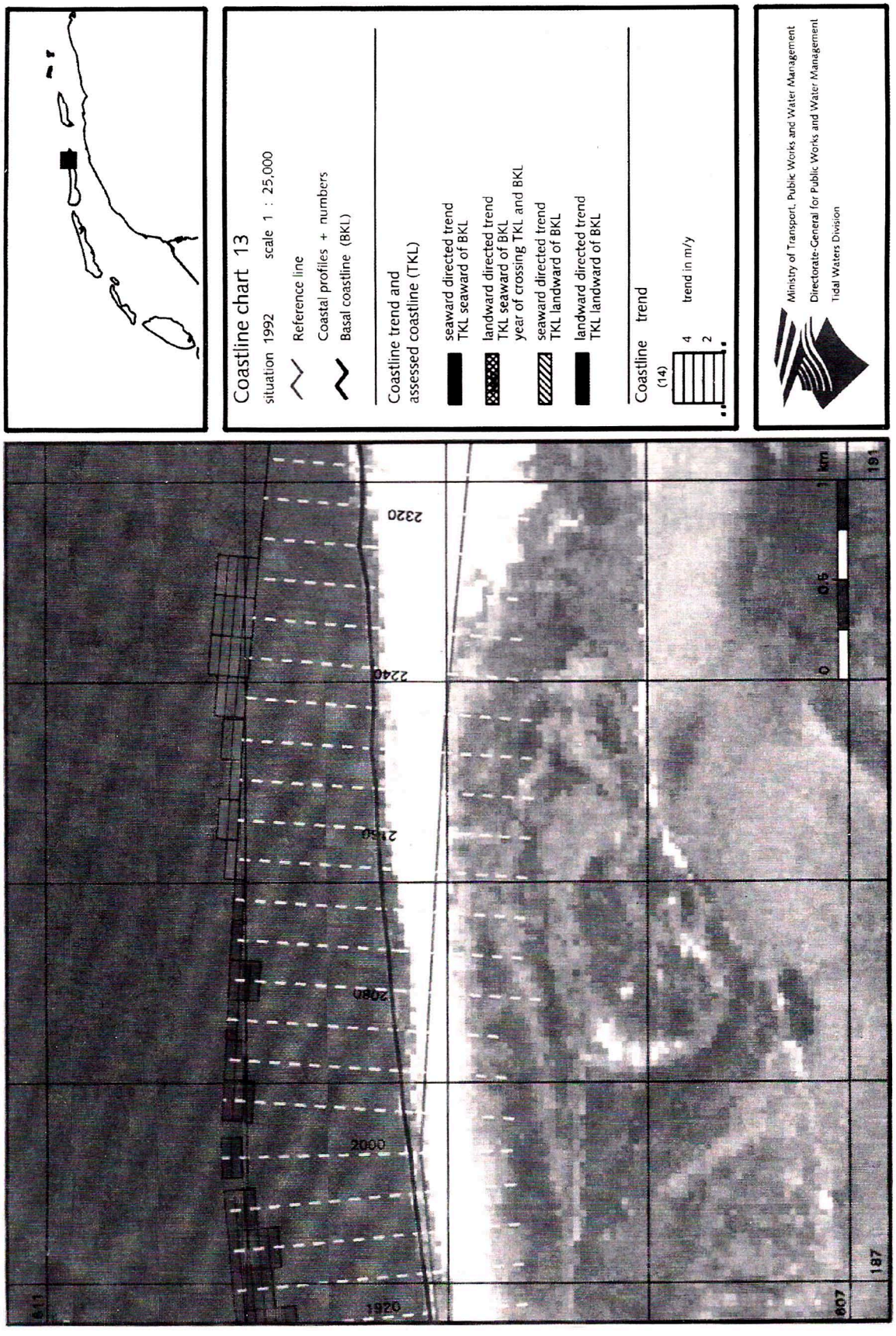

Figure 5 - coastline charts of 1992 and 1994 of the same area of Ameland island, presenting the two types of background and different bar graphs

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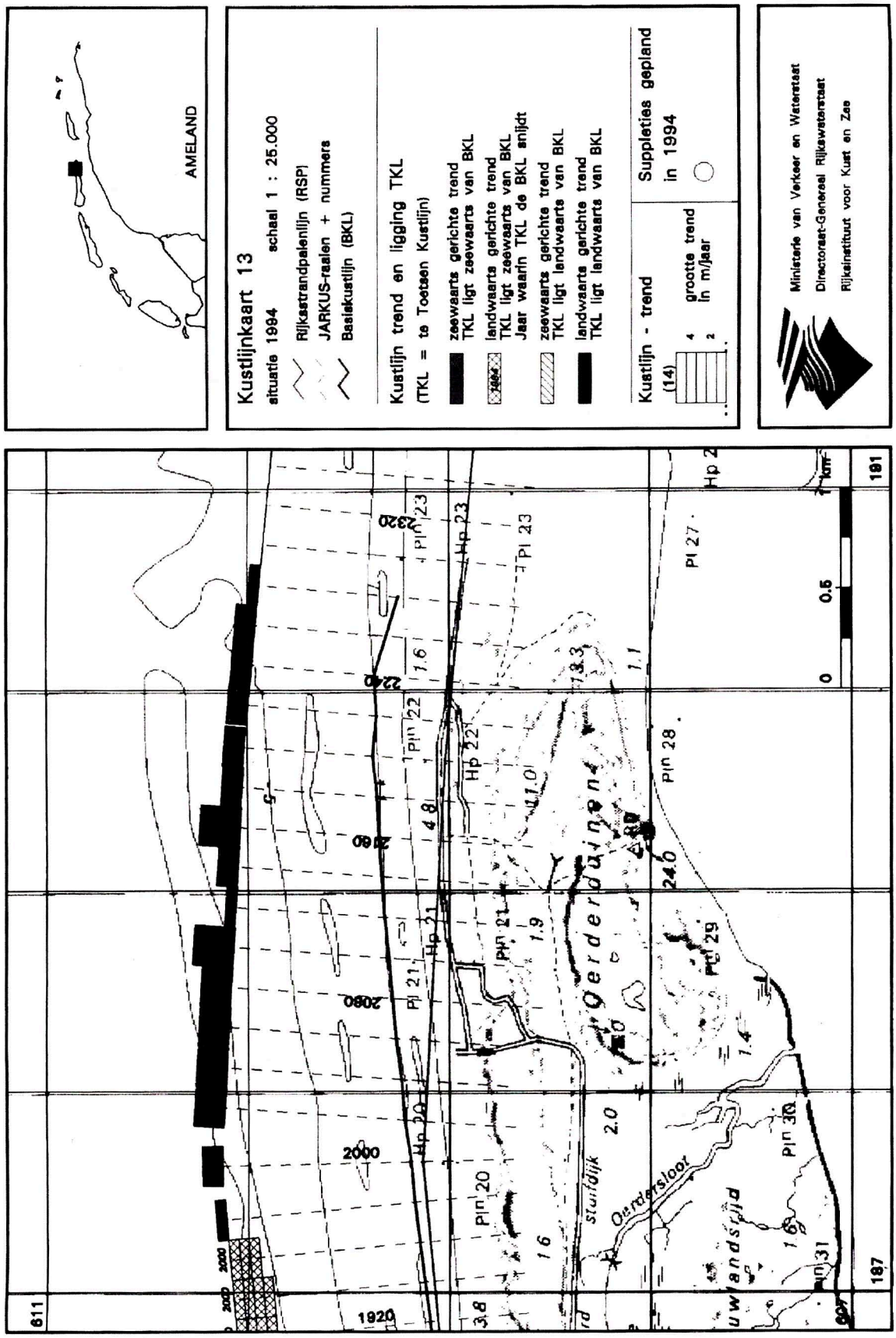

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development. With the help of a recently developed GIS-application, the SHOreline MANagement tool (SHOMAN), the effects of a slufter-system in the province of North-Holland can be analysed.

SHOMAN

The SHOreline MANagement tool (SHOMAN) is a GIS-instrument meant to assess the impacts of management actions on the development of the coastline. The SHOMAN demo is concerned with the development of a slufter along the "stretched" coastline of Holland. Such a slufter can only survive if a permanent opening to the sea exists and salt water enters the slufter regularly. How often the slufter is flooded by the sea, is in the first place dependant on the elevation of the opening and the slufter-valley. From an ecological point of view, there are certain requirements as to the size of a slufter while from a socio-economic point of view there are requirements as to the distance from build-up areas and infrastructural facilities. For these reasons the SHOMAN demo has three phases of analysis:

- In the first phase the underlying question is: which areas are available for nature development?
- Based on a limited number of datasets of the province of North Holland, specific functional land use is selected and presented on an overall chart. Around each land use aspect (e.g. roads, housing, industry) a buffer zone is created, by means of an interactive menu. In this way the distance between e.g. industry and the area with nature development can be guaranteed. Finally, when all the buffer zones are established, the "free areas" are calculated and presented on the overall chart **(Fig. 6)**.
- In the second phase the underlying question is: is the safety of the hinterland guaranteed when a slufter is developed?

In this technical/engineering phase the program is focused on the "free areas" north of Bergen aan Zee. The chart on the screen shows topographic information of the area, on top of a grid map. This elevation grid, or digital terrain model (DTM), is composed of three basic data sets: the North Sea bathymetry based on soundings; the beach area from the -5 m depth contour to 200-400 meter inland based on both soundings and orthophotos (yearly monitored), and the dune area based on orthophotos. Due to the great variation in the spatial information density, the main challenge was to create the final map with 80,000 (15 by 15 m) grid cells.

This DTM is required to determine how the dune area is flooded at specific water levels. To ensure a halophyte-vegetation in such an area, at least 2-12 floods should occur annually.

Based on data related to coastal development (erosion/accretion rates from the coastline charts) the best location for the slufter entrance can be determined.

The managers of the dunes have to safeguard the surroundings of a possible slufter area. With the TIN-module it is possible to show any cross section of the area, and compare it with the standard safety profile.

When a slufter area is developed, it is necessary to make an opening to the sea through the first row of dunes. Also some topsoil will be removed from the dunes valley, and at some locations a defence ring has to be created to guarantee the safety of the hinterland.

To simulate this process - shaping the DTM - a shovel subroutine is made. The changes in volumes are administrated, and can be used for cost calculations.

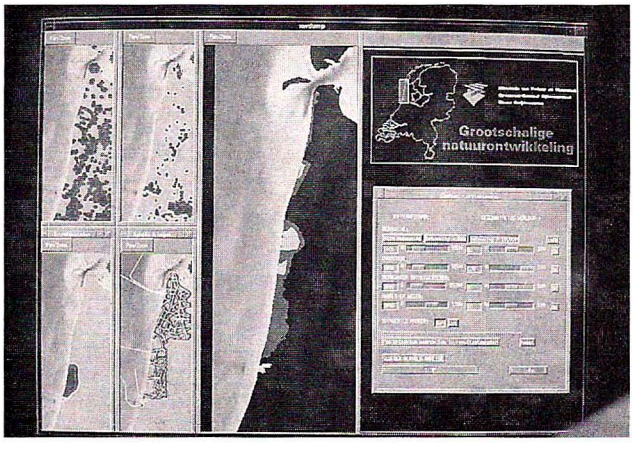

Figure 6 - SHOMAN pilot: results of phase 1

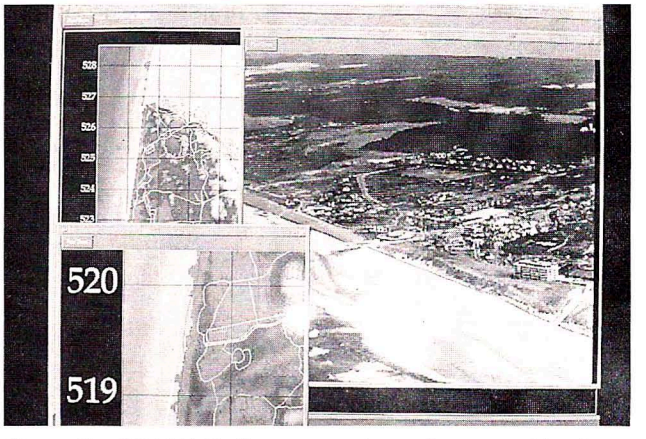

Figure 7 - SHOMAN pilot: comparison of topographic charts and oblique photograph of the pilot area

– In the third phase the underlying question is: what is the size of the slufter and what is the benefit for nature?

In the pilot-program the size and volume of inundated areas are calculated in relation to the adjusted flood-level. If digitised vegetation charts are available, then the loss of plants, trees etc. can be estimated. At present this aspect is covered by digitised information of topographic maps and digitised oblique photographs from the air and in the field.

Present Developments

It is generally expected that remote sensing and GIS techniques and instruments will be of increasing importance in coastline and coastal zone management. Present developments in this respect are:

1. The compilation of DTM's directly from images.
2. The cooperation between divisions of Rijkswaterstaat and others to exchange meta-information, datasets en GIS-applications.
3. The extension of GIS-applications for the coastal zone, e.g. SHOMAN, with multi-media aspects.

Ad 1. - An operating system converting orthophotos directly to Digital Terrain Models with the required grid size is presently developed. The greatest advantage of such a system, in comparison with the present-day analytical method, is that not only elevation contours or cross section information is available, but also all the information of the area in between. The Survey Department of Rijkswaterstaat is doing research to determine the quality of this new technique, in comparison to the conventional method. Other new developments, like laser scanning techniques to determine the elevation in terrains, are investigated.

Within a few years Rijkswaterstaat hopes that these new techniques can save time and costs in the process of coastline assessment, described earlier in this paper.

Mapping the Dutch sea bottom by Imaging Radar is a technique which was developed and validated by Rijkswaterstaat in cooperation with Delft Hydraulics. The method is promising but not yet operational. It is expected that the conventional methods to determine the depth with acoustic equipment will be used in the coming years.

Ad 2. - To carry out coastline management, a number of instruments is available: the annual coastal measurements, the acquired knowledge on coastal processes, the annual assessment and the technique of sand nourishment. Evaluation of coastline management is done every five years. The next evaluation report will be published in 1995. If necessary, some aspects of coastline management by Rijkswaterstaat or the water boards will be improved.

In most cases the local Water Board is responsible for maintenance and management of the first row of dunes, repair of the dunefoot after storm, and the planting of marram grass. To administrate some of these aspects in tables and charts, Rijkswaterstaat started a GIS-pilot called KUSTGIS.

Another GIS-pilot application, called HELMGIS, provides information on locations in the dunes where marram grass is planted. With remote sensing techniques (e.g. false colour images) the situation of the vegetation, including marram grass, can be recorded over a certain period. By comparing of these records in a GIS, the changes in vitality of marram grass can be determined. As a result, plans for replanting or the application of fertilisers can be made.

Within the organisation of Rijkswaterstaat a meta-information system called MISGEO will be set up, supported by the Survey Department. This meta-information system for geographical data is necessary to exchange information on available data sets (coverages), charts and applications. Up to now, many data sets and applications are only available within a local organisation/division. The system will be operational in the beginning of 1995.

In addition, cooperation with the local managers and Water Boards will open new archives with monitoring data. A problem that has to be solved, is that in most cases the information is not available in digital form.

Ad 3. - In the GIS-program SHOMAN not only the DTM or topographic information is presented to support the decision of a manager for a new location for a slufter. In addition about 450 oblique photographs are available, which cover the entire sandy coastline of the Netherlands **(Fig. 8)**. This aspect is rather new in the GIS-environment. It can be considered as a first step in the direction of a Multi-Media Decision Support System for the Dutch Coast, which can include sound, voices and short video shots.

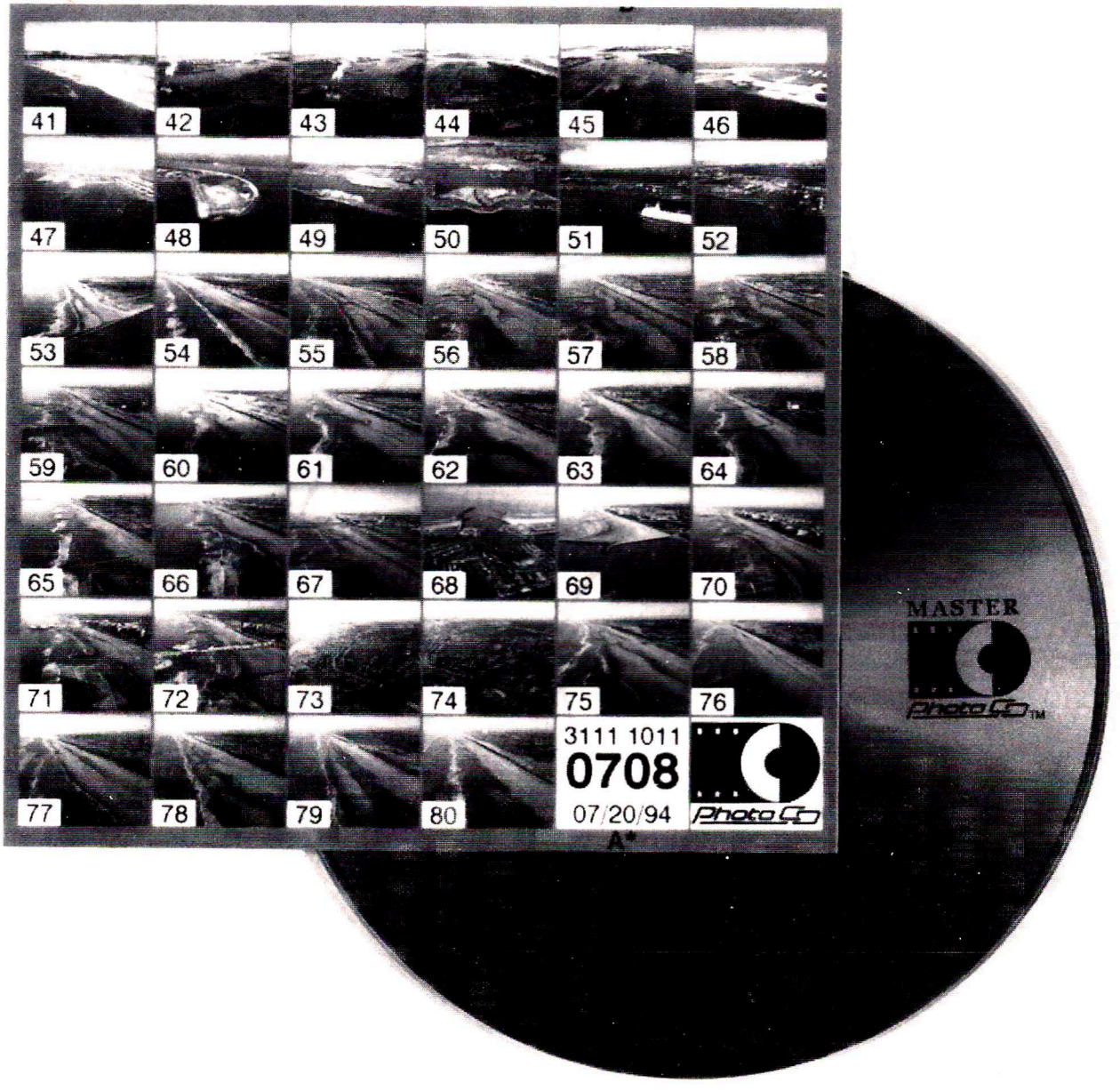

Figure 8 - Oblique photographs of the Dutch coast in digital form

For an efficient coastal zone management the use of a GIS and a MISGEO-system can be of great help. In this respect, it is concluded that the fact that information is available, is more important then the format in which it is available (e.g. report, spreadsheet, database). Present developments in GIS and RS technology are such that major improvements in coastline management and coastal zone management can be expected before the year 2000.

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