Groundwater modelling of a coastal dune using remote sensing and GIS

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ABSTRACT

A groundwater model is developed to support optimisation of the functions of groundwater abstraction and nature conservation for a coastal dune in the south-western delta of the Netherlands. In the past decades, wet dune slacks and the associated rich vegetation have degenerated due to a structural drop of groundwater level, as a result of excessive groundwater exploitation. Recently, an experiment has been started to regenerate two formerly wet dune slacks. In order to increase the model's suitability for eco-hydrological analysis, a wide range of data (available maps, field data, remote sensing data) is stored in an information system (DeltaGIS). The data, variable in time and space, is used to generate input as much as feasible by means of a GIS. Special attention is paid to the modelling of phreatic groundwater.

This paper focuses on the handling of the different types of data throughout the modelling process, i.e.: (i) an increase of the model's spatial resolution, (ii) the use of a DTM with steady state modelling results to indicate potential wet sites, (iii) the use of high resolution remote sensing data for mapping vegetation structures and for regionalization of evapotranspiration, and (iv) the use of time series of precipitation, evapotranspiration and piezometric levels for input, calibration and validation of the transient flow model. Modelling results are stored in the information system, to evaluate the effects of interventions in hydrology and water management on the site factors of the wet dune slacks (scenario studies).

INTRODUCTION

During the past decades ecohydrological research in the Netherlands resulted in valuable methods and techniques to predict the effects of changes in hydrology and water management on the site factors of aquatic and terrestrial ecosystems. Most of this knowledge has been gathered in nature conservation areas that are affected by dehydration of wet and moist ecosystems. This dehydration of vegetation and fauna is the direct negative effect of a structural drop of the groundwater level. It can be the result of a number of indirect causes as well, e.g.: decreased seepage intensity as a result of changing groundwater flow patterns or the inlet of polluted surface water or artificial recharge to compensate for groundwater shortages.

Public Drinking Water companies in the Netherlands produce and supply drinking water, water for industrial use and irrigation water for agricultural use **(Fig. 1)**. Dutch drinking water is produced from groundwater (65%) and surface water (14%) that is artificially recharged after prepurification, mainly in the coastal dunes on the mainland of the Netherlands facing the North Sea **(Fig. 2)**. A total yearly amount of ca. $900*10^6$ m^3 of groundwater and artificially recharged surface water is abstracted. The remaining 21% is directly produced from surface water. The abstraction of groundwater and the infiltration of the eutrophic river Rhine and Meuse water into the soils of the oligotrophic coastal dunes contribute to the dehydration and eutrophication of nature and landscape.

According to the Dutch Groundwater Law, licenses are required for the above mentioned activities. Issued by the

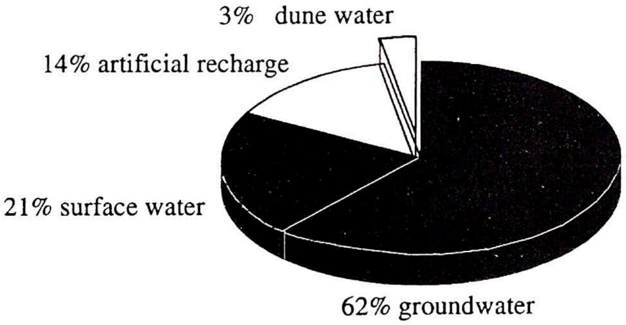

Figure 1 - Where Dutch drinking water comes from (after Vinkers, 1991)

provincial authorities, in order to obtain these licenses, drinking water supply companies are increasingly forced to carry out research on the ecological effects of geohydrological changes. Ever more attention is given to the ecological impacts of measures which result in higher water tables.

At present, experience in regeneration of former groundwater abstraction areas and surrounding nature conservation areas is very limited. However, in the coastal dunes of the Netherlands numerous activities are undertaken for ecohydrological optimisation (Jansen, 1992).

This paper describes a research project aiming at the optimisation of groundwater abstraction and nature development in a coastal dune area in the south-western delta of the Netherlands. Within the framework of an integral systems approach, the handling of different types of data throughout a groundwater modelling process is discussed. Further attention is focussed on refinement of a groundwater model of the dune area, to make it more suitable for ecohydrological purposes. This is achieved by: (i) an increase of the model's spatial resolution, (ii) grid-based calculation of selected input variables, and (iii) transient flow modelling.

The groundwater modelling results and the derived thematic maps will be used to predict the possibilities for restoration of former wet dune slacks and their characteristic vegetation.

ENVIRONMENTAL PROBLEM DEFINITION

Geomorphological development of the coastal dune

The dune area Oranjezon comprises a series of alternating parallel dune ridges, and formerly wet slacks, on the peninsula of Walcheren in the south-western delta **(Figs. 2-4)**. The dunes constitute a relatively small and narrow groundwater recharge area (386 ha) with a maximum width of 1 km. **Fig. 4** shows a SPOT panchromatic satellite image of the coastal dune and its adjacent polder area (8/15/91). Main types of land use in the polder (situated below mean sea level (MSL)) are agriculture and small scale urbanisation.

Geomorphological development of Oranjezon since 1200 A.C.. is illustrated in **Fig. 5** (Slikker and Stokvis, 1975). Since the middle ages the dune gradually expanded in north-eastern direction, while erosion by tidal currents dominated along the western shore. Here the for dune is prevented from further erosion by protective measures and the construction of a sand dike (1983). A range of dunes and dune slacks (originally sandy shore, first cut off from the sea, subsequently blown out) has been deposited on former tidal flats. These tidal flats are found as a clayey layer at MSL **(Fig. 7)**. Some of the dune slacks in the east were connected with open sea until 1910 (e.g. Tweede Kreekgat, **Fig. 5**).

Groundwater abstraction

Since 1882, groundwater is abstracted for public water supply from the dunes of Oranjezon. Due to relative low population densities of the adjacent region (according to Dutch standards), artificial recharge has never been necessary. Nevertheless, with the increasing amounts of abstracted groundwater, problems related to capacity and saltwater doming occurred frequently. From 1940 until 1984 between 800,000 and 1,000,000 m^3 water was withdrawn annually.

If we assume that annual maximum possible groundwater abstraction from the area equals the natural groundwater recharge, since surface runoff is negligible, a rough water balance calculation leads to the following. The catchment (V) of an area (A), of about 300 hectares with an average yearly precipitation (P) of 750 millimetres, (V) amounts to about 2.25 million m^3/yr. Through actual evapotranspiration (ET_{act}) by soil and plants about two thirds are lost, leaving 0.75 million m^3/yr as the natural groundwater recharge (ΔV):

A = 300 ha (750 acres)
ET_{act} = 500 mm / year
P = 750 mm / year
$\Delta V = (P - ET_{act}) * A = 0.75 * 10^6\ m^3$ / year

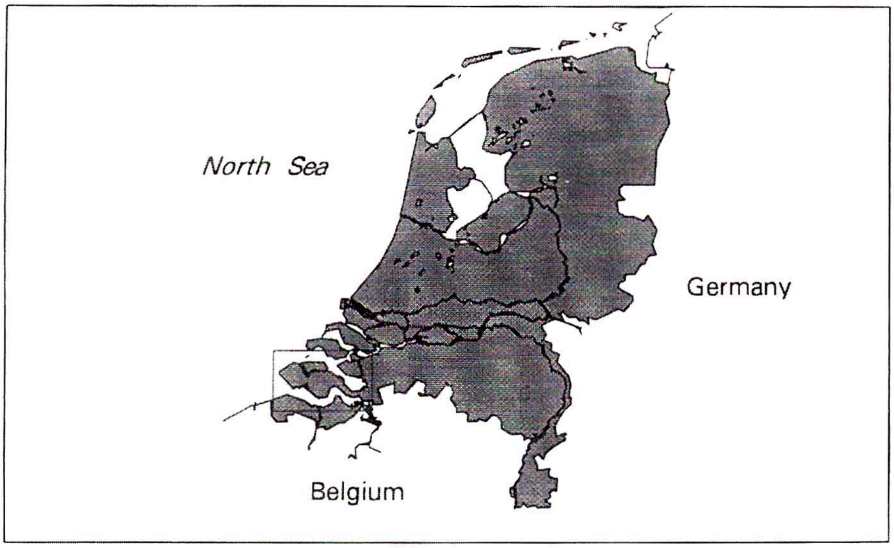

Fig.2 The Netherlands

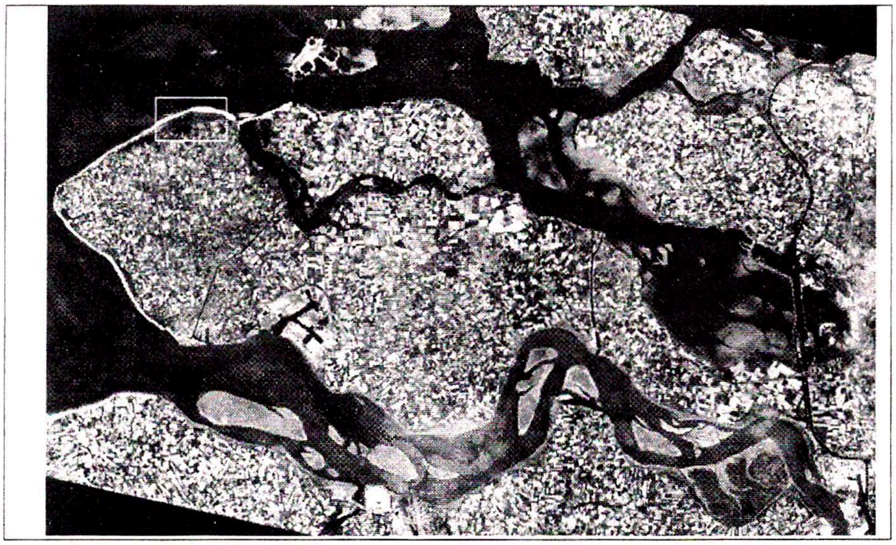

Fig.3 Southwest delta

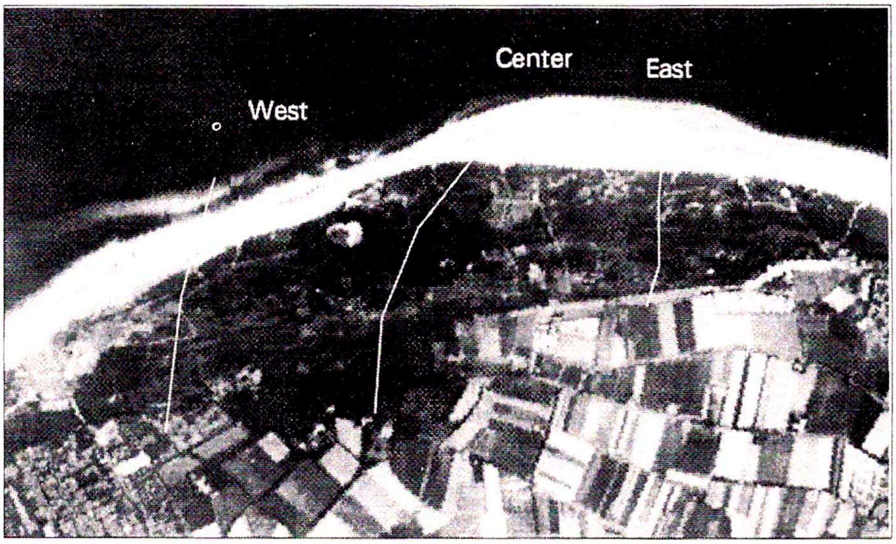

Fig.4 Research area Oranjezon

Images: (c) CNES

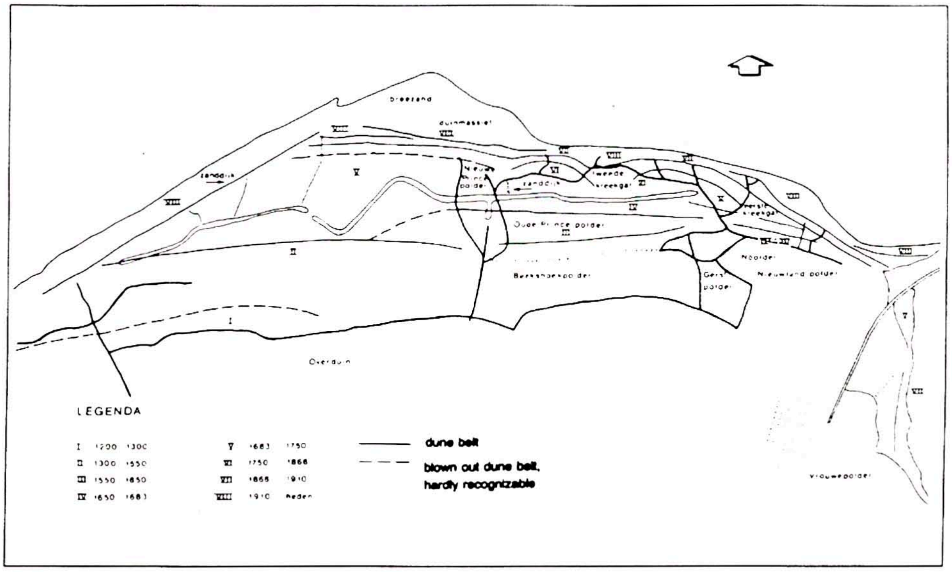

Fig.5

Geomorphology since 1200 A.C.

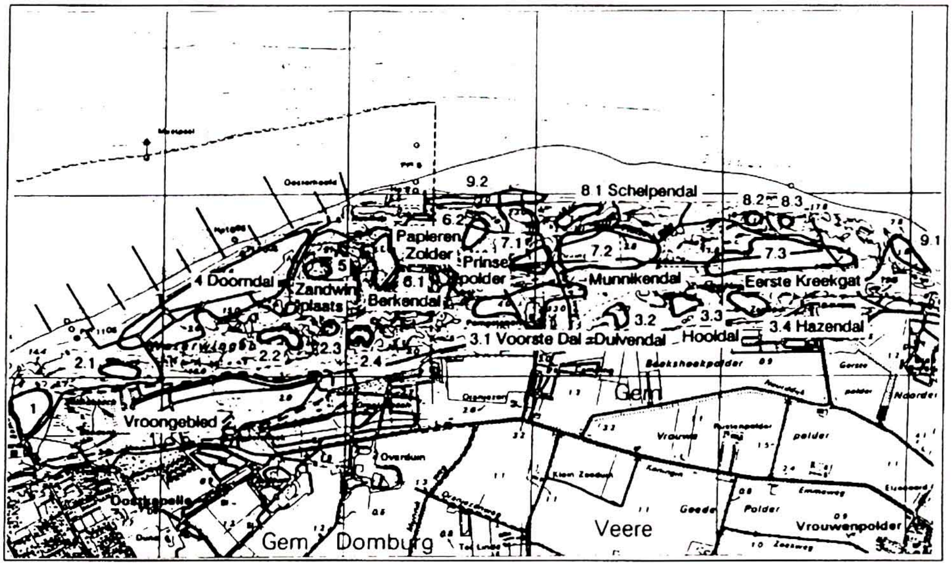

Fig.6

Situation of dune slacks

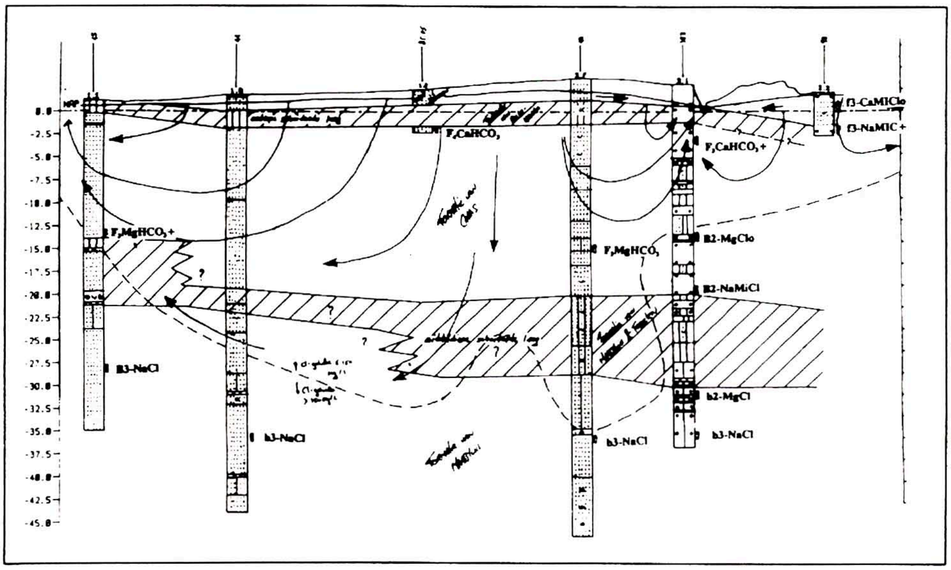

Fig.7

Central cross-section

B3-NaCl = Watertype

The maximum abstraction exceeded 1 million m3 in 1967, which was in relation to recharge far too high. Since 1984, groundwater abstraction has been reduced to less than 400,000 m^3 per year. Presently, groundwater abstraction in Oranjezon contributes only 0.04 % to the 3 % of natural dune water abstraction in the Netherlands **(Fig. 1)**.

Vegetation since 1900

Floral descriptions by Heimans and Thijsse (1899) and Sipkes (1917 and 1920) indicate that, at the beginning of the century, especially in the western part of the area, wet dune slacks were abundant. From these historical descriptions it was possible to deduce which slacks were wet and had valuable types of vegetation at that time. A reference situation for regeneration of wet dune slacks could be set up by making use of knowledge on the degree of eutrophication, acidity and the stage of succession (Duin & Kust, 1989). The present condition of the dune slacks is known from field surveys (Heidemij, 1976; Duin & Kust, 1991; Krause, 1993; Bakker and de Hamer, 1993) and remote sensing data (Hobma, 1993). The present dune slacks are coded according to their sedimentological history and will be described below **(Fig. 6)**.

Around 1900, many species characteristic for the wet dune slack habitat, moist or wet, oligotrophic, moderately acid or calcareous conditions of the soil, were found in the western part (no. 6.1 and 6.2), e.g.: Parnassia palustris, Dactylorhiza incarnata, Epipactus palustris, Pyrola rotundifolia and Ophioglossum vulgatum.

In the south-west, conditions were suitable for moderately succesful agricultural use (Vroongebied): moist or wet, moderately acid conditions of the soil, grassy, rich in humus content and grazed by sheep and cows. It is unknown whether the small agricultural parcels had already been abandoned at the time. Characteristic species for these conditions like Orchis morio were encountered. Radiola linoides and Anagallis minima were likely to be present as well, but were not reported.

East of the pumping station (situated between no. 7.1 and 7.2), hardly any wet dune slacks with characteristic vegetation were encountered. Dune slacks were in the initial stage by then, due to the connection with open sea until 1910. Species that are indicative for brackish conditions were encountered, e.g.: Glaux maritima, Puccinellia maritima, Limonium vulgare.

The environment of the present decoy-farm in the south-west was already completely decalcified, in view of the report on Eriophorum angustifolium. Two small brooks flowed into the adjacent polder from here, in which Hottonia palustris was found. This indicates eutrophic conditions of the stream banks. Young dune slacks (e.g. no. 4) were, by then, characterised by typical pioneer species of wet oligotrophic conditions, e.g.: Centaurium littorale, Centaurium erythraea, Sagina nodosa and Samolus valerandi.

A significant lowering of groundwater levels in Oranjezon (0.5-1.5 m since 1882) has been caused by various developments in the past decades, e.g.: excessive groundwater exploitation, afforestation with pine (to prevent blowouts), a stop of grazing, succession towards increasing encroachment of shrubs and trees, changes in the position of the coastline and intensive drainage in the adjacent polders. The resulting reduction of the water budget of the coastal dune has led towards a severe decrease in nature values. Characteristic vegetation types of wet sites almost completely disappeared. On the decalcified boggy soils thick thorn shrubland and dry grassland with encroachment of woody species have become dominant. Only along the open drainage canals **(Fig. 5)**, a few species indicative for mesotrophic to eutrophic wet and moist conditions are encountered. Species like Centaurium erythraea, Dactylorhiza majalis and Dactylorhiza incarnata, that are found along the upper section of the canal's slope, indicate that groundwater and soils are not too much eutrophic for future restoration of oligotrophic conditions.

Regeneration of wet dune slacks

Due to the described intervention in (water) management of the coastal dune an unbalanced situation developed in the past decades. But since some years, increasing value is set upon the worth of the area as a nature conservation area. In the water management plan of the provincial authorities (Province of Zeeland, 1992), two main functions of Oranjezon are assigned: groundwater abstraction and nature conservation. In order to bring about a more balanced situation regarding these equally important interests, it was decided to carry out a sort of ecohydrological optimisation of the coastal dune. This may be understood as: the adjustment of bussiness management in and the rearangement of the groundwater abstraction area in such a way that both groundwater abstraction and nature benefit. In the provincial water management plan the existing groundwater abstraction is considered a fact, although the negative effects on nature should be minimised.

Since 1991 experiments have started in Oranjezon that aim at the regeneration of wet dune slacks and the associated vegetation. Since 1992, this has resulted in the abstraction of groundwater being limited to the western part of the area. Regular grass cutting and large scale grazing by cows have been re-introduced in July 1991.

At the end of 1992, in the eastern part of the area, the dune slacks Munnikendal (no. 7.2) and Eerste Kreekgat (no. 7.3) have been restored to their original (abiotic) situation as much as possible. At first, the present vegetation, mainly encroachment of shrubs and young trees, was mown. The remaining organic matter, together with the upper 25 cm of humic and sandy layers of the soil, was used to fill up the former abstraction canal at the site. With the initial digging of the canal in the twenties, the paleosols of the former tidal flats, presently encountered as a discontinuous clayey layer at MSL **(Fig. 13)**, were broken. A plastic foil was used for restoration of the aquitard at the site of the canal.

GROUNDWATER MODELLING PROCESS

Integrated systems approach

To predict the effects of the present and future impacts to hydrological changes on wet dune slacks, a groundwater model of the coastal dune is being optimised using different types of data. This is done within the framework of an integral systems approach. Various thematic maps and time series, have been taken from independent studies to improve the groundwater model for ecohydrological interpretation: a geohydrological survey and steady state groundwater model (Iwaco, 1988), a hydrochemical facies analysis (HYFA; Bakker and de Hamer, 1993; Hobma et al., 1994), a local ecohydrological study (Krause, 1993), and a remote sensing classification of dune vegetation and evapotranspiration (Hobma, 1995).

The above studies have been carried out to obtain knowledge on the complex interrelationships between groundwater and ecolology of the coastal dune, i.e.: (i) to identify the extent of groundwater flow systems related to the hydrogeology of the subsoil, and the interactions with the flow systems of the adjacent North-sea and marine polders, (ii) to analyse the development of the hydrochemical composition of the groundwater along the flow- or path lines of these flow systems, (iii) to provide insight in the interactions between groundwater, surface water and vegetation of the dune slacks, and (iv) to assess the use of high resolution satellite remote sensing for mapping vegetation structure and estimation of evapotranspiration and consequently groundwater recharge.

For the storage, analysis and presentation of the resulting spatial data, it was decided to test and use a recently developed information system on water and environment. Here the system is referred to as DeltaGIS (Hobma and Bottelier, 1994) or geohydrological data base. Three different software packages are being used: Arc/Info (Esri, 1993) for geographical data; Erdas (Erdas, 1991) for remote sensing data; and Micro-Fem for steady-state and transient flow groundwater modelling using finite elements (Hemker and Van Elburg, 1990).

Nine successive steps in groundwater modelling

The overall groundwater modelling process can be characterised by nine successive steps:

1 Determination of the appropriate level of aggregation,
2 Selection of the most appropriate and available model (software),
3 Conceptual model of the (geo)hydrological system,
4 Imposing boundary conditions,
5 Gathering of field observations,
6 Refinement of the model and its input parameters,
7 Calibration and validation of the groundwater model,
8 Performance of scenario studies,
9 Visualisation and interpretation of thematic maps and tables.

In this study the optimum level of aggregation has been determined in the first place by (a) the desired ecohydrological results, i.e.; piezometric heads of the groundwater in time (in m), infiltration and seepage values (in mm/day) and flowpaths of groundwater flow systems at the level of the dune slacks **(Fig. 6)**. These requirements had to be balanced by a feasible level of the available sources of (b) model input, i.e.; soil parameters, terrain levels, meteorological data, vegetation structure, (c) reference data, (d) boundary conditions and (e) available hardware.

Once the first two steps have been taken, the actual modelling process (steps 3-8) is initiated. The overall data flow is depicted in a flow chart **(Fig. 8)**. Thematic maps of the model's (initial) input parameters can be derived by means of data integration and spatial analysis, and consequently be stored in the geohydrological data base. The calcula-

Table 1 - Characteristics applied in the groundwater modelling of Oranjezon coastal dune

FEM-CALC, FEM-CAT MODELLING DOMAIN		**Characteristics applied in modelling of Oranjezon coastal dune**	
		General model	Refined model
x-y spacing:	number of nodes: <0,∞>	708	2627
	spacing between nodes: <0,∞>	100	50
time interval:	between time dependent data:	mean dry/wet period	month
	calibration period:	1985	jan1985-dec1993
	type of simulation:	steady-state	transient flow
no. of layers:	maximum number of aquifers (i):	3	3
	Per node/nodal area:		
	NP: net precipitation [m/day]	annual, rough zonation	monthly, grid-based ($10*10\ m^2$),
	h_0: surface water level [m]	variable in dune water abstraction canals, fixed in polder ditches	
	Per layer:		
	h_i: piezometric head [m]	h_3 is fixed and h1 is fictive in polder area	
	d_i: discharge [m^3/day]	$d_2 > 0$ in abstraction wells in the coastal dune	
	kD_i: transmissivity [m^2/day]	kD_1 fictive layer in polder, kD_3 calculated for fresh water layer	
	c_i: vertical resistance [day]	incl. drainage resist. dune canals ($c_{2,3}$) and polder ditches (c_1)	
	S_i: Storage coefficient [-]	relevant for transient flow, when $i < 3$, since h_3 is fixed	

tion modules (Femcalc and Femcat) use the input data to calculate and update attribute values in an iterative procedure, on the basis of a finite elements network (with x,y spacing), a number of layers (in z direction) and for a specific period or number of time steps (t_j; **Tab. 2**). With the use of two independent sets of reference data the modelling results can be calibrated (i.e. tuned on field measurements) and validated, which will result in the model's accuracy (Stroet, 1993). By performing selected scenario studies, the effects of changes in hydrology and water management can be evaluated. The resulting piezometric heads, fluxes and flow paths in time can be presented and processed into thematic maps, graphics and tables. This may be achieved trough overlay techniques with locational information or through combining attribute information using statistical or spatial modelling techniques (step 9).

In the following the refinement of the Oranjezon coastal dune groundwater model and its input parameters (step 6) is discussed.

OPTIMISATION OF THE ORANJEZON GROUNDWATER MODEL

The aim of the refinement of the general groundwater model of Oranjezon is to make the model more suitable for ecohydrological interpretation. Since the moisture condi-

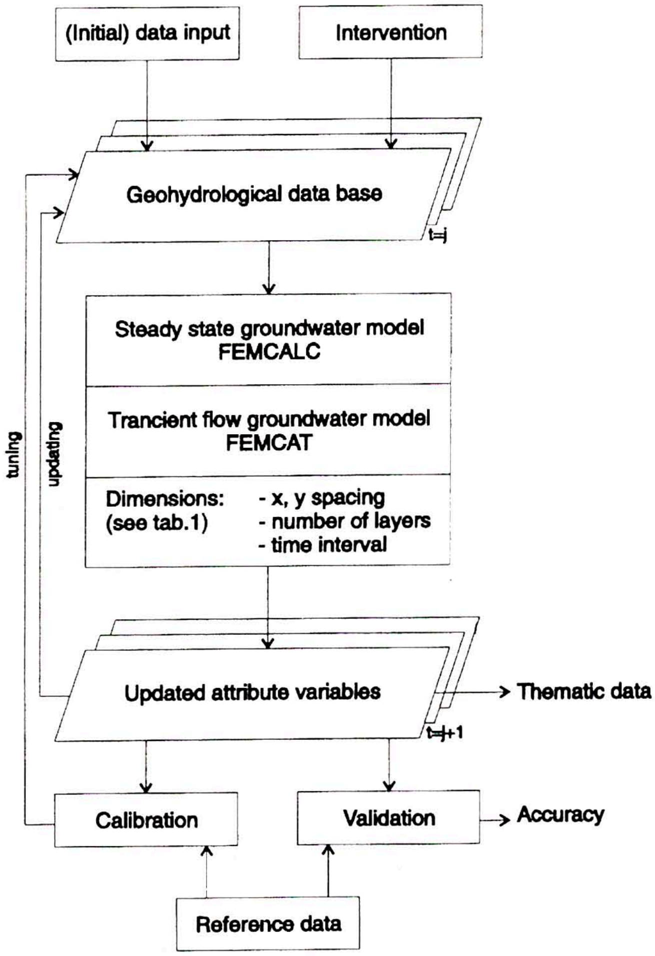

Figure 8 - Overall data flow in groundwater modelling (t_j= time at interval j)

tion of the soil is considered to be a major factor for restoration of the wet dune slacks, special attention is being paid to the detailed modelling of the phreatic groundwater. Other factors determine the quality of the wet dune slack vegetation as well, e.g.: humus, nutrient and calcium content of the soil, (micro) relief, vegetation structure, supply of nutrients from the surrounding environment, possibilities for blow out and cultural-historical aspects (Koerselman, 1992; Hobma et al., 1994). These will not be discussed here.

The steady-state groundwater flow model

The general steady-state groundwater model is based on a geohydrological schematisation of the coastal dune in three waterbearing layers (kD_i, i..3; **Tab. 1**). These aquifers are separated by aquitards: a thin clayey layer (c_1) at MSL **(Fig. 13)** and a middle-deep clayey layer (c_2, at 20 m. -MSL; **Fig. 14**). In the horizontal plane, a finite element network (708 nodes) was constructed that represents the boundary conditions of the water-catchment area (h_i along coast-line, canals and polders) as close as possible **(Fig. 11)**. Given the extensions of the original model and the capacity of the program at the time (Iwaco, 1988), mean nodal distances within the dune segment amount to 100 m. A sharp fresh/brackish interface was calculated in the third aquifer **(Fig. 7)** using the Badon-Ghyben relation. Transmissivities of the deep aquifer (kD_3) were calculated on the basis of the thickness of the fresh water layer (D_3). Resistance values (c_i) were used to simulate both the two aquitards and drainage resistances of the hydrological infrastructure within the coastal dune and the polders. Groundwater is withdrawn from the model through two canals (h_0) and two rows of abstraction wells ($Q_{1,2}$). Net precipitation (NP) was estimated on the basis of normal precipitation (P), mean annual open water evaporation (E_0) and a rough zonation of five types of vegetation structure, at dry and wet conditions (Bakker, 1981). The year of calibration was 1985.

A sensitivity analysis of the general steady-state model (Iwaco, 1988) showed that calculated phreatic groundwater levels (h_1) to a large extend depend on the vertical resistance of the first aquitard (c_1) and the net precipitation (NP). Therefore the optimisation of the Oranjezon model involved: (i) an increase of the model's spatial resolution (nodal spacing), (ii) grid-based ($10*10m^2$) calculation of selected input variables (p_i ; **Fig. 9**) and (iii) transient flow modelling.

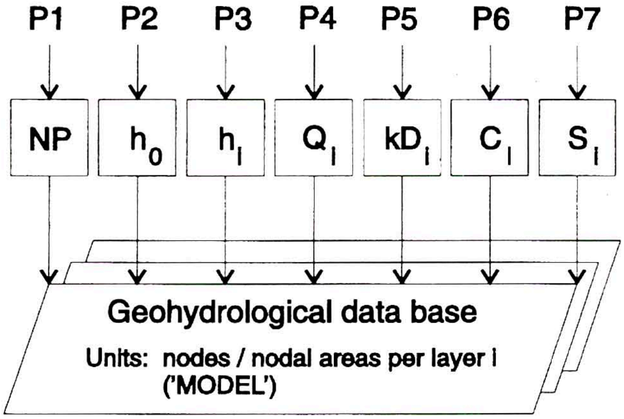

Figure 9 - (Initial) data entry.

Increasing the model's spatial resolution

Halving mean nodal distances in the finite elements network (50 m; **Fig. 11**) resulted in a quadruplication of the number of nodes (2627; **Tab. 1**) and an equal reduction of nodal area **(Fig. 15)**. This enables a more accurate simulation of the shallow clayey layer, with use of additional field data and intervention maps (c_1; **Tab. 2**; **Fig. 10**).

Grid-based calculation of net precipitation

A procedure has been developed for grid-based calculation ($10*10\ m^2$) of net precipitation (NP = p_1; **Fig.9**). The procedure comprises three stages the core of which is depicted in **Fig. 16a**. Maps of soil moisture classes (5) and vegetation structure classes (27) were gridded and combined into maps of evapo-transpiration classes (26 ET-cl) by means of a look-up table (LUT-operation). A second look-up table has been used to relate the maps of ET-classes to monthly calculated net precipitation (NP) values per ET-class. This procedure has been repeated for the monthly time intervals t_j (j = 1..120; starting in January 1985), and taking into account the different input maps before and after the restoration of the wet dune slacks (j = 93; October 1992). Consequently, for each time interval NP-values have been averaged per nodal area. The resulting maps and tables have been stored in the geohydrological data base.

Calculation of soil moisture maps

The procedure to produce the maps of soil moisture classes is shown in **Fig. 16b**. At first, two digital elevation models (DTM) of the model area have been constructed by integration of: (digitised) x,y,z-points from topographical

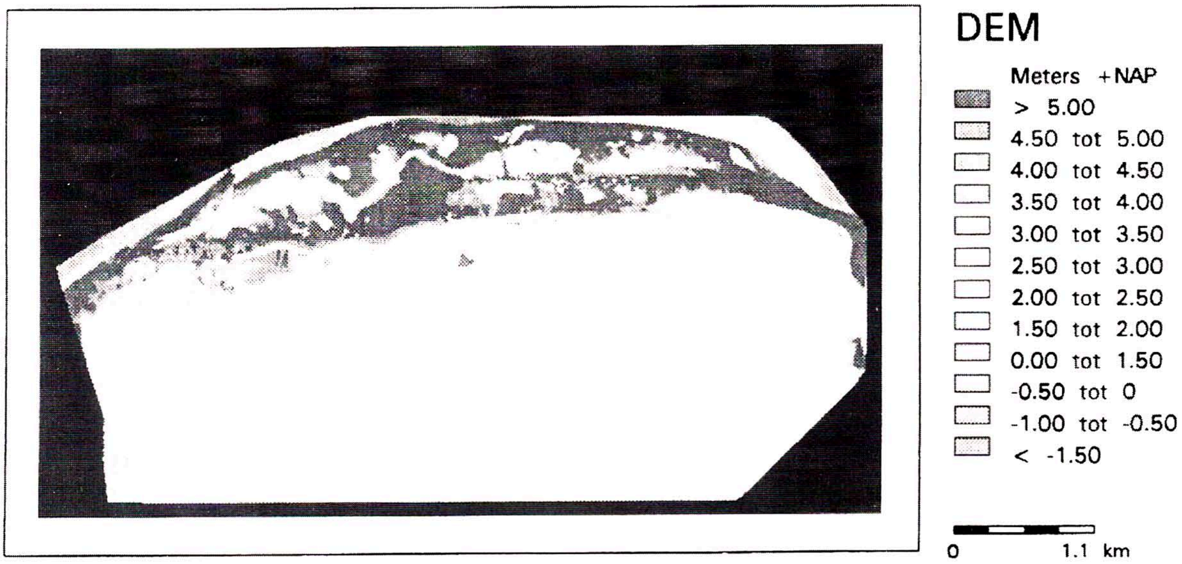

Fig.10

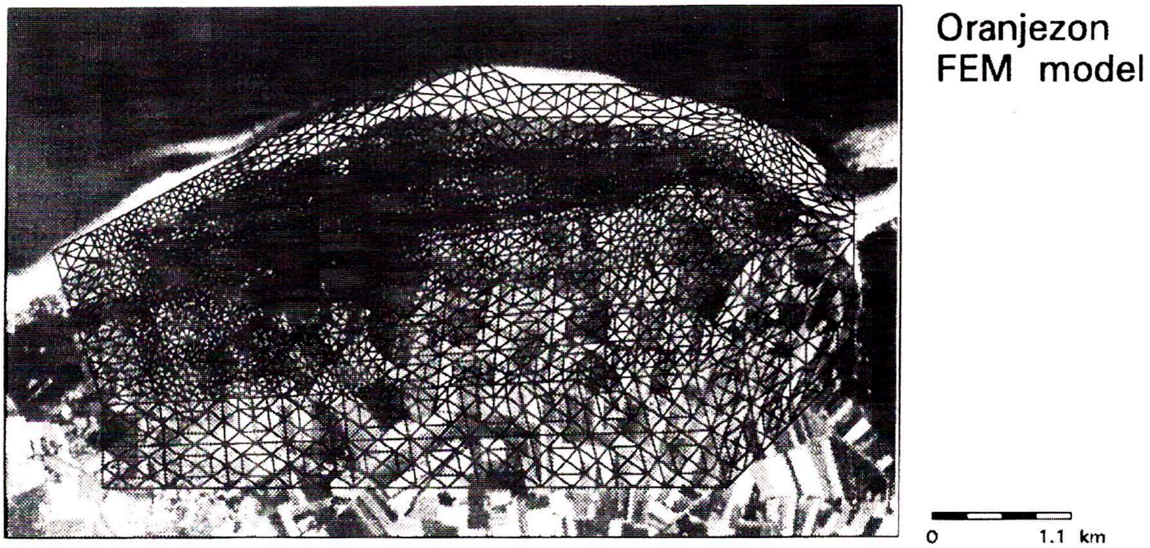

Fig.11

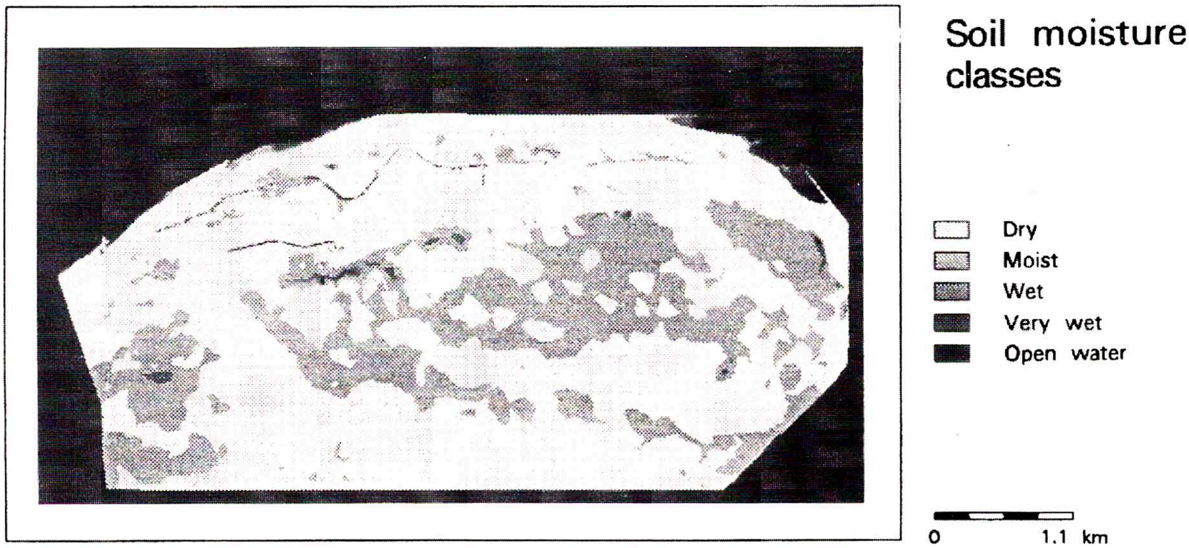

Fig.12

DeltaGIS data

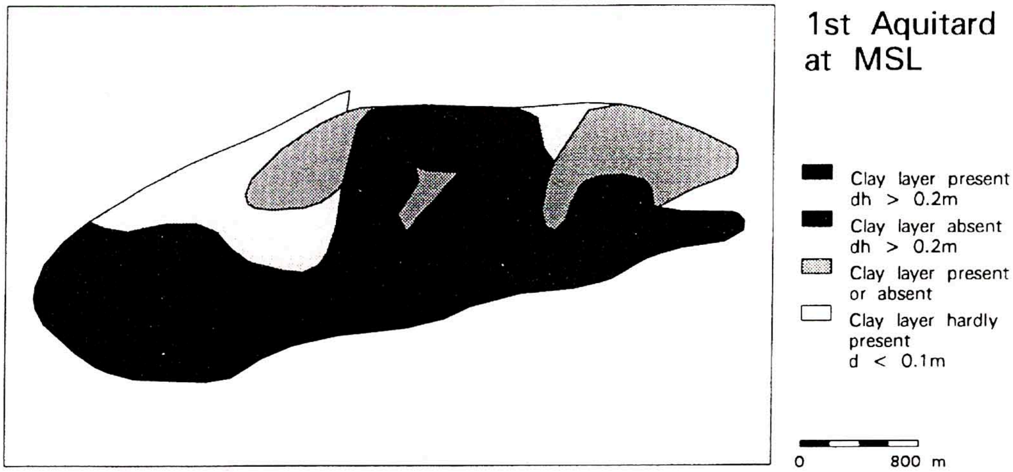

Fig.13

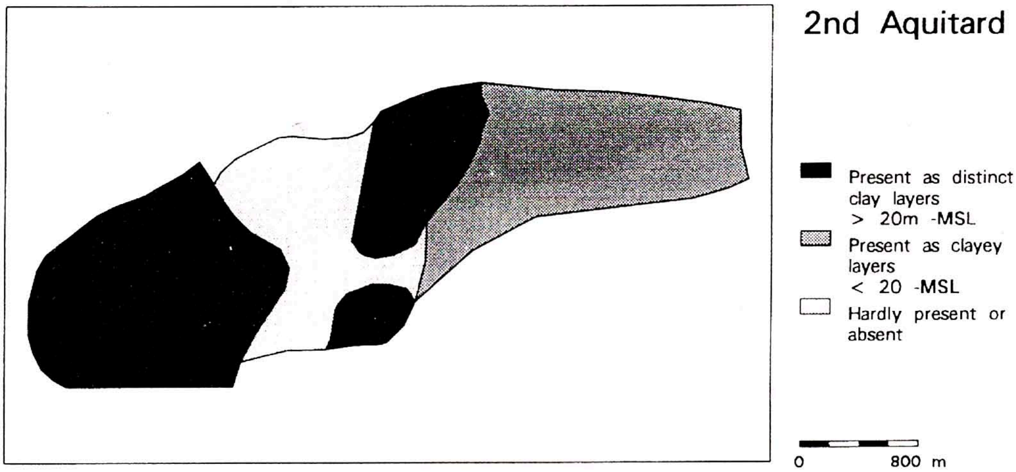

Fig.14

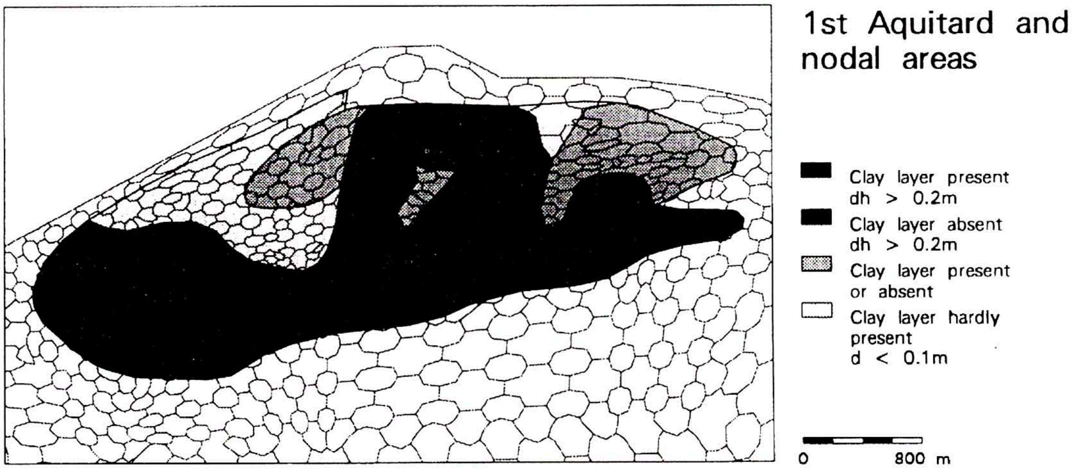

Fig.15

DeltaGIS data

maps of the dune (1:2000) and polder area (1:10,000), field measurements and intervention maps (j > 93; **Fig. 10**). Maps of surface levels (in m ± MSL) and mean annual groundwater tables (in m ± MSL), resulting from steady-state calculations, were gridded, subtracted from each other and classified into five moisture classes **(Fig. 12)**:

1 dry	(GWL < 0.9m -SL)
2 moist	(0.9m -SL ≤ GWL < 0.3m -SL)
3 wet	(0.3m -SL ≤ GWL < 0.1m -SL)
4 very wet	(0.1m -SL ≤ GWL < 0.2m +SL)
5 open water	(GWL ≥ 0.2m +SL)

Wet classes (3-5) in the soil moisture maps match fairly well with the potential wet sites in **Fig. 6**. Finally, a re-classification into two soil moisture classes (wet/moist and dry) was made. These were used to discriminate the 26 evapotranspiration classes ($p_{1.1}$; **Fig 16b**).

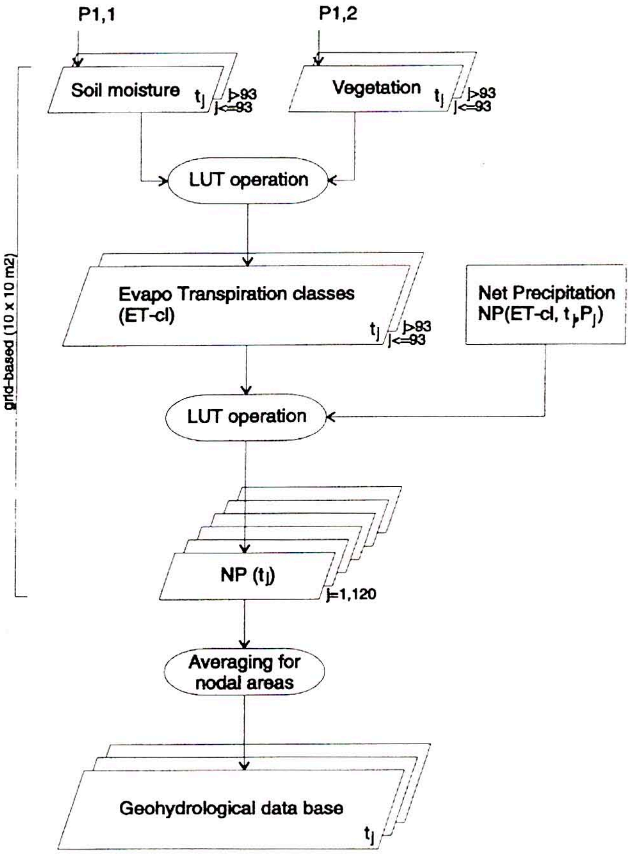

Figure 16a - Procedure for mapping net precipitation (NP; p_1)

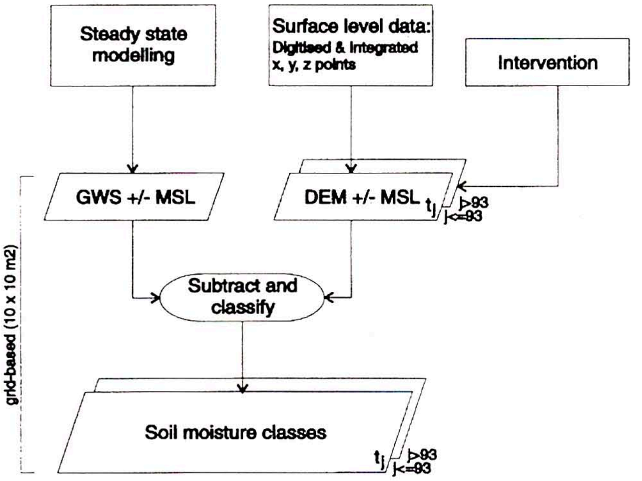

Figure 16b - Procedure for mapping soil moisture classes ($p_{1,1}$)

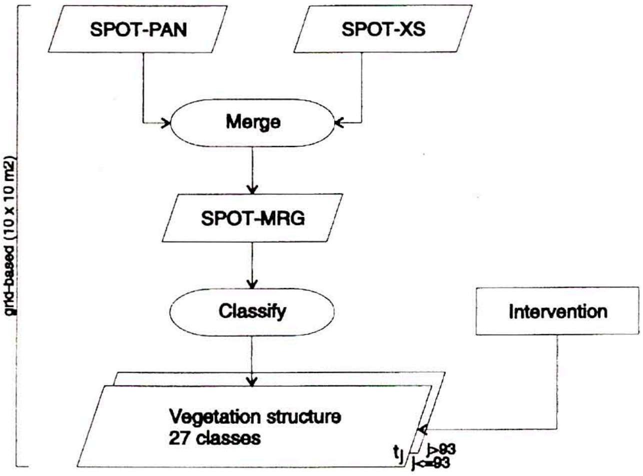

Figure 16c - Procedure for mapping vegetation structure ($p_{1,2}$)

Classification of vegetation structure maps

A multispectral and a panchromatic SPOT image (SPOT-XS and SPOT-PAN) of the south-western delta of the Netherlands (Augustus 25, 1991), were georeferenced and resampled to the pixel size of the panchromatic image (10*10 m). Thus providing the geometrical basis for the other grid-maps. Merging of SPOT-XS and -PAN was then performed according to the algorithm of the Radiometric Method (Pellemans et al., 1993). In the resulting image from merging (SPOT-MRG) the better spatial and spectral resolution of the panchromatic and the multispectral image respectively were combined (Hobma, 1995).

Two supervised classifications were performed on the SPOT-MRG image; one resulting in a vegetation structure map of the coastal dune (14 classes), the other in a land use map of the adjacent polder area (13 classes). Both maps were joined and the result was overlayed with the inter-

Table 2 - Variable settings and calculation of transient flow model parameters

par.	fixed/variable in time	startvalue (tj, j=1) derived from:	next values (tj, j>1)derived from
NP	variable	integration various data sources (**Fig. 9**)	integration various data sources (**Fig. 9**)
h_0	fixed/variable	map	water management / intervention maps
h_i	variable	steady-state calculations	transient flow calculations
Q_i	variable	map	water management / intervention maps
kD_i	fixed/variable	fixed: maps & steady-state calculations variable (i=1): $D_1 = h_1$	if var.: transient flow calculations
C_i	fixed/variable	fixed: maps & steady-state calculations variable (i = 1): c_1 <0,∞>	if var.: intervention maps
S_i	fixed	table	table

vention maps of the wet dune slacks. This resulted in two vegetation structure maps for two periods with $j \leq 93$ and $j > 93$ (27 classes) ($p_{1,2}$; **Fig 16c**).

Transient flow modelling

Transient flow modelling experiments have recently started. The storativity term (S_i) was added to the data set to account for storage of groundwater in time in each node (**Tab. 1 and 2.**). Calibration of the refined model is now being done in time and space, by comparing time curves and grid-maps of simulated and observed piezometric heads, and calculated and observed water balance data in time.

Scenario studies will involve present and future interventions at the sites of the former wet dune slacks and different amounts of abstracted groundwater from the coastal dune.

CONCLUSIONS

In the groundwater modelling process of Oranjezon coastal dune a wide variety of data types is applied to improve the model's suitability for ecohydrological interpretation. Special attention is being paid to the detailed modelling of the phreatic groundwater, since the moisture condition of the soil is considered to be a major factor for restoration of the wet dune slacks. Analysis of data flows and a sensitivity analysis of the steady-state groundwater model provided insight in the procedures needed for optimisation of the input data for the transient flow model and the ecohydrological interpretation of modelling results.

When simulating phreatic groundwater levels and shallow groundwater flow systems, considerable improvements on the model's accuracy, are expected by making use of remote sensing in a procedure for enhanced estimation of net precipitation, as a model input. Parts of the procedure are still to be improved, e.g. by the use of a high quality digital elevation model (DTM) of the coastal dune, instead of a DTM that is rather dated and was partly derived from contour lines. In addition, an increase of the model's spatial resolution and incorporation of accurate field knowledge on the situation of the first shallow aquitard (at MSL) at the sites of the wet dune slacks will contribute to an improved accuracy of the ecohydrological tool.

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