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APPLICATION OF THE HYDROLOGICAL MODEL GRODRA FOR THE DESIGN OF A WATER MANAGEMENT SYSTEM IN THE LAND CONSOLIDATION PROJECT GIETHOORN-WANNEPERVEEN

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INTRODUCTION

Both in, wet regions where excessive precipitation has to be discharged and in arid regions where irrigation is applied, the most common form of water resources management is control of the surface water system. In the Netherlands, where much of the land lies below sea level and a substantial inflow of water occurs via precipitation and a number of major rivers, the traditional water resources management aimed at drainage and discharge of excess water. In the course of time an intricate system of waterways, pumping stations, sluices and weirs, combined with a dense network of ditches and drains developed. Nowadays the system is essential for protection against inundation and for control of the groundwater table in order to provide soil moisture conditions amenable to agricultural production in both wet and dry periods.
For this reason particular attention has been paid to the interaction of groundwater and open channel flow in a physically based hydrologic response model that has been completed recently at the Delft Hydraulics Laboratory. This model, which has been named PREDIS for its description of precipitation - discharge processes has been constructed as a series of self-contained computer modules each concerned with a specific part of the hydrological cycle. The modular interpretation of the classical portrait of the hydrological cycle underlying the structure of PREDIS has been depicted in Figure 1. The model PREDIS (Gilding and Wesseling, 1983) and the coupling of groundwater and open channel flow (Crebas et al., 1984) have been presented earlier. The present paper focusses on the modules for saturated groundwaterflow and drainage to open channels. The combination of these modules, named GRODRA, provides a valuable tool in situations where the groundwater table is controlled by management of the open channel system.

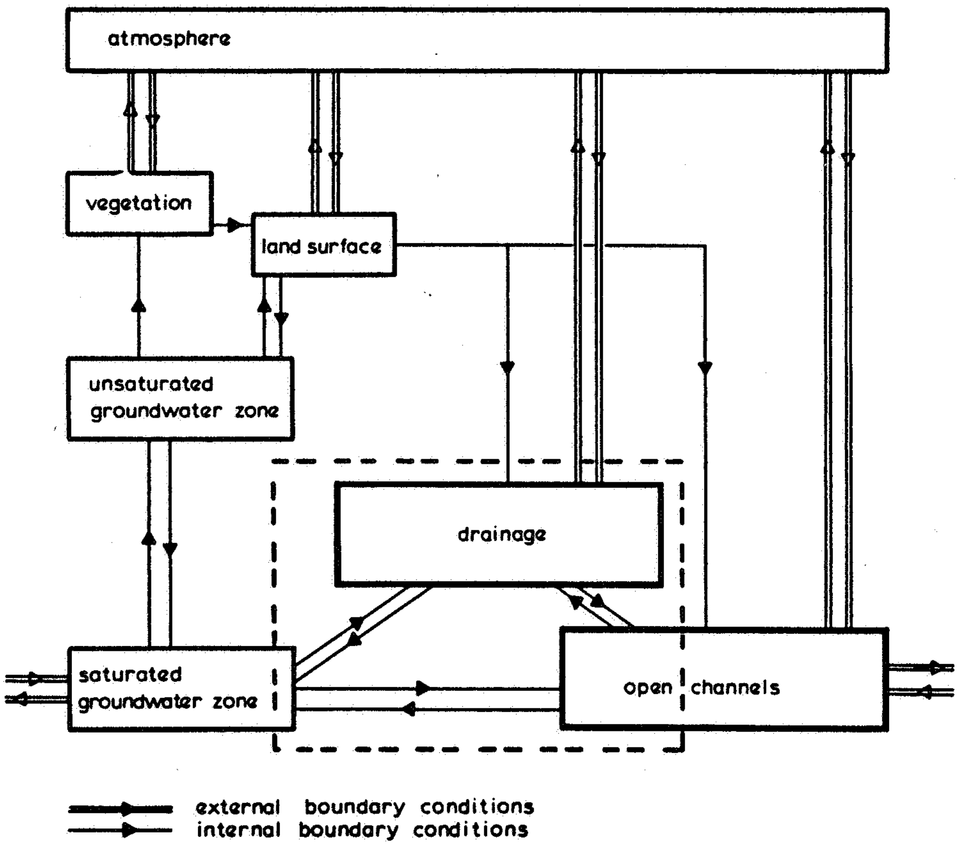

Figure 1 Modular interpretation of the hydrological cycle in the hydrologic response model

CONCEPTUAL BASIS OF GRODRA

In the general structure of the hydrologic response model, the surface water system has been divided into two subsystems.
The first subsystem comprises the large waterways in which the flow and storage effects are significant. The main function of this system, which will be referred to as the open channel system, is to collect the water from the smaller conduits and discharge it to one or more points outside the region concerned. The water level in the open channel system provides a boundary condition to the smaller conduits that discharge to it. PREDIS comprises a special subroutine to compute the water level in the open channel system as a function of flow, storage and the operation of regulating devices. However, very often the water level in the open channel system can be fully controlled by opreation of regulating devices. In those cases, for computational purposes, the water level in the open channel system can be assumed to be a given state variable.
The second subsystem, which will be referred to as the drainage system, is concerned with all the small conduits discharging to the open channel system. These conduits would require too much refinement to be considered individually on a regional basis, but amalgamated they have an important in-

fluence on the hydrologic behaviour of a region.
GRODRA has been designed for those situations where the water level in the open channel system is fully controlled. The saturated groundwater flow and seepage to the drainage system then are the two processes that govern the hydrologic behaviour of the region.

The module for saturated groundwater flow is based upon a schematization of the flow regime into a number of highly-permeable horizons alternating with poorly permeable layers.
In the main aquifers it is supposed that the Dupuit-Forcheimer assumption of essentially horizontal flow may be applied. The interaction with the drainage system is supposed to take place in the uppermost phreatic layer.
The exchange between this aquifer and a drainage conduit is formulated as a function of the groundwater head and a drainage resistance.
For the mathematical description of the exchange funtion an expression, based on the formulae for drainage design, is used in which the most important physical properties of the drainage system are represented.

MATHEMATICAL REALISATION

By analogy to Darcy's law (or Ohm's law) the exchange between the phreatic aquifer and a drainage conduit is formulated as:

$$Q = (\phi - h)/R \qquad (1)$$

in which d denotes the groundwater potential, h the given open conduit water level and R the drainage resistance.
In the module for saturated groundwater flow the spatial component is treated by a Galerkin finite-element technique, using quadrilatic elements.
The method yields an approximate solution of the form:

$$\phi(x,y,t) = \sum_{i=1}^{n} \phi_i(t)\ v_i(x,y) \qquad (2)$$

where $\phi_i(t)$ are the computed groundwater potentials in the nodal points of the grid and v_i is a series of basic functions.

If for each element of the grid the drainage resistance can be computed from the physical characteristics of the drainage system in the element and the open conduit water level is given, the exchange can be computed by combination of equations (1) and (2) with the equation for groundwater motion.
To define the drainage resistance and the open-conduit water level for the various elements of the grid, the following assumptions have been made:
- the effects of storage in the drainage system may be neglected
- the drainage system can be divided into various subsystems,

each discharging to a point of the open channel system with a defined potential
- the water level within each subsystem may be regarded as uniform
- the drainage systems can be characterized by a limited number of prototype drainage conduits which may be regarded as parallel and equidistant
- the overall influence of the drainage system can be incorporated from the prototype conduits by the principle of superposition.

In GRODRA, the drainage resistance for a prototype conduit has been based upon the Hooghoudt-Ernst formula and reads (Ernst 1962, Streltsova 1974, Van Beers 1976):

$$R = (1/\pi K_2) \ln(\eta D_2/p) + \rho/p \qquad (3)$$

where η is a geometrical shape factor, ρ is an entrance resistance accounting for the hydraulic impedance of material lining the bottom of the drain, p is the wetted perimeter of the drain and K_2 and D_2 refer to the hydraulic conductivity and the thickness of the aquifer below the line of drainage.

APPLICABILITY OF GRODRA

GRODRA can be applied for those situations where a strong interaction between groundwater flow and open channel flow occurs provided that the potential in the open channel system can be controlled.

The program contains a formulation to compute a drainage resistance based on the physical characteristics of the system. For practical applications one is however free to define the various drainage parameters in such a way that the behaviour of the system under consideration is simulated in the best possible way.

As an example of the approach the Giethoorn-Wanneperveen investigation will be presented.

APPLICATION IN THE GIETHOORN-WANNEPERVEEN PROJECT

The Giethoorn-Wanneperveen project area is situated in the northern part of the Netherlands. The area comprises some 5000 hectares of marshland with a rich flora and fauna and is of particular interest from a point of view of nature and landscape conservation. High groundwater tables and small and dispersed agricultural plots are hampering a proper cultivation of the land and limit the agricultural development. The land consolidation project aims at improvement of the conditions for agricultural development in one half of the area, while in the other half the requirements of nature and landscape prevail. Figure 2 shows the lay-out of the project area.

Improvement of agricultural conditions can be realised by adaptation of the surface water system, aimed at enlargement of agricultural plots and reduction of the groundwater head.

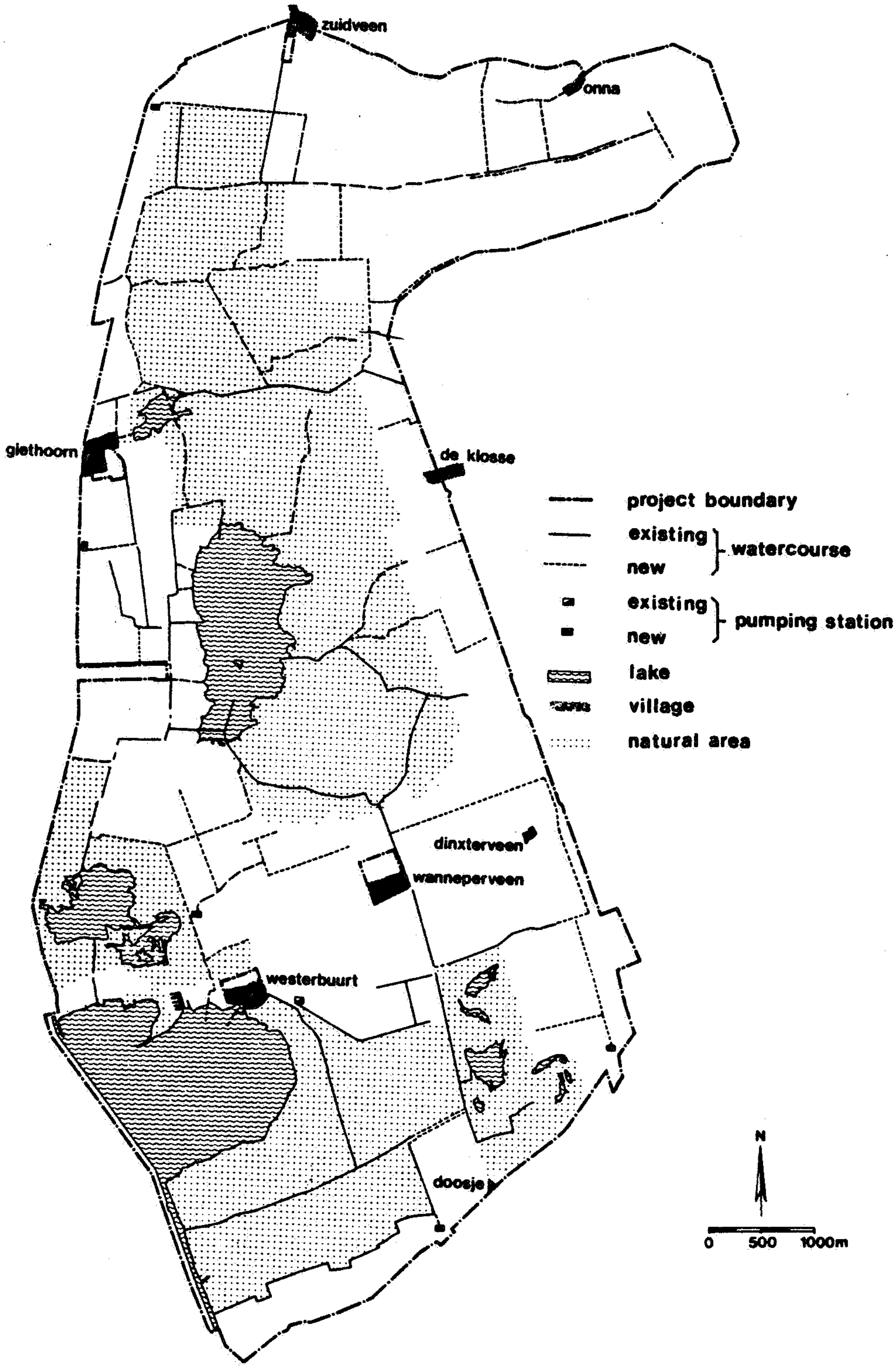

Figure 2 Landconsolidation project „ Giethoorn–Wanneperveen

Conservation of nature and landscape however, require a constant or even increased groundwater head. The conflict between the interests of agriculture and nature conservation is deteriorated by the geohydrology of the area; since the peaty toplayer is underlain by a permeable sandy aquifer (Fig. 3). Possibilities for recharge to the nature area by external supply are limited by the chemical characteristics of the available water which originates from Lake IJssel.
Though the water quality of Lake IJssel is satisfactory for agricultural use, abundant supply to the nature area may cause a considerable change of its vulnerable vegetation.

The conflicting interests of agriculture and nature conservation and the strong hydrological interactions between the various parts of the project area required a careful design of the water management system. During the process many alternatives have been evaluated. The program GRODRA has been used to simulate the hydrological effects of the various project alternatives. Subsequent post processing was done to translate the hydrological effects in terms of agricultural production and natural values.

The design of the model has been based on the geohydrological schematization presented in Figure 3. The model comprises a phreatic aquifer and a semi confined deep aquifer separated by an aquitard.

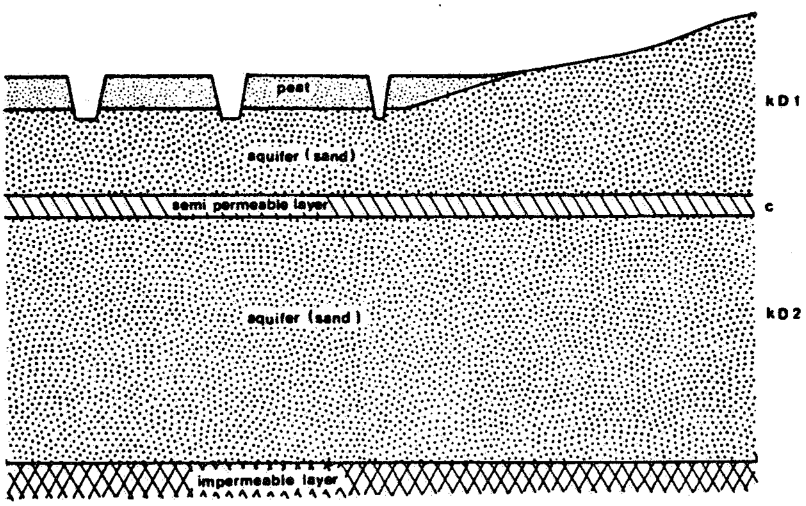

Figure 3 Geohydrological schematization

The influence of the peaty toplayer has been neglected in the groundwater model; but has been accounted for in the interaction with the surface water system, by specification of an increased entrance resistance term in Equation (3).
In the model the surface water system has been represented by four classes of open conduits. The characteristic parameters

for each of the classes are presented in Table 1.

class	bottom depth (m)	bottom width (m)	side-slope
1	1,20	0,50	1:1,25
2	1,40	1,40	1:1,25
3	1,50	2,00	1:1,50
4	1,90	2,50	1:1,50

Table 1 Subdivision of drains in classes

The spatial variation in the surface water system has been accounted for by specification of a drain-density parameter for each of the four classes in the various elements of the finite element grid.

In the first phase of the study a model has been designed covering the entire project area and some 3400 hectares of adjacent land. Thus the boundary conditions of the model would not be influenced by changes of the groundwater and surface waterhead within the project area. The finite element grid of this model comprised 131 elements. The model has been used for calibration of the geohydrological parameters and for calculation of the overall effects of various project alternatives. For model calibration observed groundwater heads and measured discharges of three pumping stations were available. In particular the drainage resistance appeared to be a sensitive model parameter. The calibration runs demonstrated the models ability to give a satisfactory representation of the hydrologic behaviour of the area.
In subsequent phases of the investigation more detailed models have been developed, covering only part of the project area, to simulate the effects of local measures. The boundary conditions for these simulations have been derived from the results of the over-all model.

The model simulations showed that in the present situation only little of the strong seepage flow that once caused the development of the typical nature in the northern part of the area has remained. Only the drains along the eastern border are fed by seepage from the higher sandy soils adjacent to the project area. From the major part of the surface water system in the northern natural area infiltation to the groundwater occurs. In summer periods the water demand for the entire project area amounts to about 50,000 m^3/day.
Implementation of the project will cause a decrease of the surface water head in the agricultural land of the northern part of the area. As a consequence the phreatic level in the natural part will decrease with about 30 cm in those parts adjacent to agricultural plots, reducing to less then 5 cm at a distance of 1000 m from the boundary between natural and agricultural land. The water demand for the northern part of the project area will increase by some 6,600 m^3/day.

In the southern part of the project area, the surface water head will locally be increased by implementation of the project. Here the project will have positive effects on nature, since infiltration of surface water with a poor quality will be reduced.

A hydrological and ecological survey has been prepared in order to monitor the effect of the projects' implementation. Though the main drainage system has only been completed in 1982/83 and the adaptation of field drains is still in progress, some preliminar conclusions can be drawn. The groundwater flow can be represented by the scheme drawn in Figure 4. The observed chemical composition of the groundwater indicates that underneath the natural area the groundwater draining from the high sandy soils at the eastern side of the project area mixes with the infiltrating surface water.
Detailed observation of the groundwater head showed that the interaction between the groundwater and a deep canal along the western border of the project area is less strong then has been assumed in the model. Apparently the permeability of the canal bottom which was supposed to penetrate the peat layer is still relatively high.
In general however, the observations show that the predicted effects seem to agree with reality.

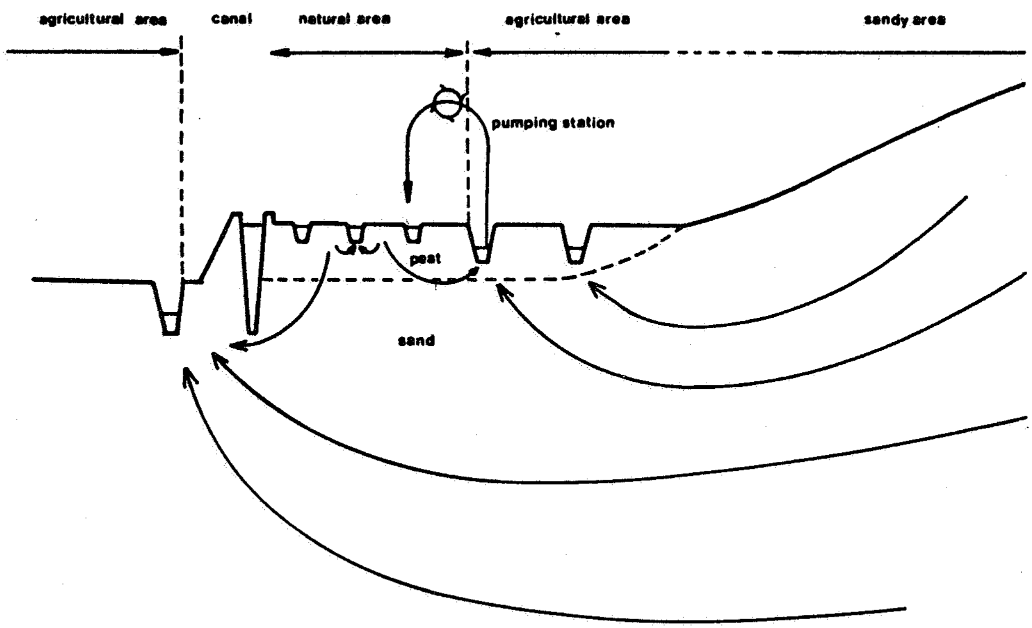

Figure 4 Schematical presentation of the groundwater flow

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