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MODELS FOR INTEGRATED WATER MANAGEMENT IN THE SOUTHERN PEEL AREA

Dr. R.A. Feddes and Ir. J. Drent

Projectgroep Zuidelijk Peelgebied 7

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I. INTRODUCTION

The main objective of the study is to develop an approach to analyze and evaluate alternatives for the management of groundwater and surface water resources with respect to both water quantity and water quality, for regions where agriculture, nature as wel as municipal and industrial water supply have important and partly conflicting interests. Objectives of the main categories involved are:

Agriculture - Farmers are aiming at an economically optimum result under conditions of an efficient farm management.

Municipal and industrial water supply - The only objective is the safe and continuous delivery of sufficient water of good and constant quality on an economically and socially justified basis.

Nature management - The objective is the creation of such conditions that diversity and mutual relationship in nature are quaranteed as well as that the existing value of nature is maintained at a quantitatively optimum level or shall develop in that direction.

In order to develop a suitable model approach one needs an experimental area in the field that can be used as a test case of the models. The aim of the research project and the restricted research capacity limits the maximum area under investigation to about 20,000 ha.

We found that area in the eastern part of the province of North Brabant: the Southern Peel area (fig. 1). A short description of the area is given below.

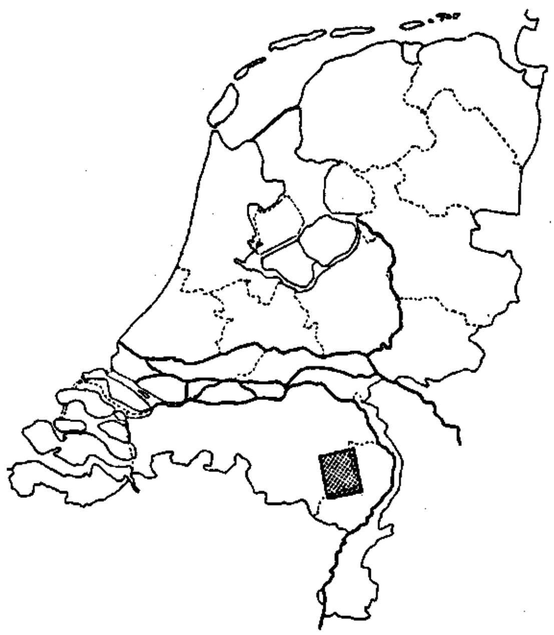

Fig. 1. The location of the Southern Peel area on the map of the Netherlands

Topography

The land surface slopes gently from about 30 m above-sea level in the east to about 20 m above-sea level in the west. Pleistocene and holocene sands constitute a highly permeable aquifer. The Peel boundary fault divides the area in two geological units. The thickness of the water bearing formation at the east side is at some places not more than 10 m. At the west side it increases to 100 m.

The area is drained by a few brooks which rise on the easterly divide not far from the provincial boundary. These brooks flow west ward parallel to the slope of the land surface. Most of these water courses are very narrow and have shallow stream channels. The population density is a few below the country's average.

Soil use

Agriculture in the region is very intensive, with a stocking rate of about 6 standard live stock units per hectare. A standard live stock unit is defined as the added value equivalent of different types of live stock expressed in that of a dairy cow. Such a standard live stock unit has a nitrogen production of 102, 6 kg N per year in slurry. About 50% of the agricultural soils are in use as grass land, 40% as arable land and 10% as horticulture. About 85% of the arable land is used for the growth of fodder maize.

Water supply

In the pilot region there are two pumping stations for municipal and industrial water supply. They withdraw about 10 million m^3 per year from the groundwater. At this moment 3 m^3 per sec. can be taken in from external sources. Because of the sandy soils farmers extract in dry periodes a lot of water from the groundwater for sprinkling their crops.

Nature

On the east and the south side of the region there are two nature reserves (1, 650 ha respectively 1, 850 ha). In this reserves there are relicts of vegetation which belong to an original vast big complex. Because of human influence (peat digging and improvement of drainage) the actual ecological importance of these parts of the region only a few relicts of the original wood vegetations also indicate a very intensive human influence.

This report gives an impression about the research progress at this moment in the project 'Optimization of regional water management' of the Institute for Land and Water Management Research (ICW).

It is a result of discussions of the model group of the project. Participating were: P. J. T. van Bakel, W. van Doorne J. Drent, R. A. Feddes, L. F. Ernst R. H. Kemmers, P. E. Rijtema, J. H. A. M. Steenvoorden P. T. Stol, J. Vreke and K. E. Wit.

II. MODEL APPROACH

To focus ideas one can put the three categories agriculture, water supply and nature at the corners of the triangle which are connected by a number of fysical models (fig. 2).

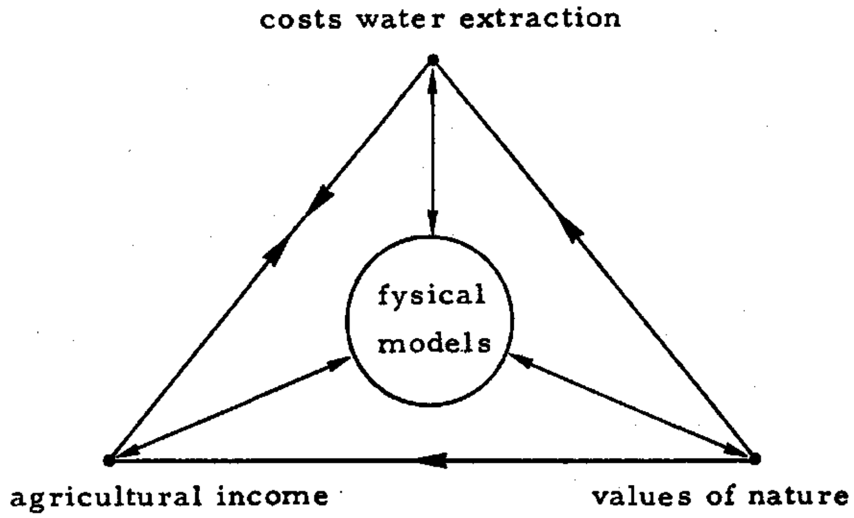

Fig. 2. Schematical representation of the three competing categories of water users

Agricultural income - The output of the agricultural model is the development of the agricultural income. This development is characterized by the mean income and the distribution around this mean. To be able to characterize income, one needs to know the fysical production functions, i. e. relationships of water use versus crop yield and fertilization versus crop yield. In addition information about the effect of farm management actions on water management is required, such as sprinkler irrigation from surface/ground water, crop schedule, overdosing and dumping of manure, degree of mechanization, etc.

Costs water extraction - The quantity and quality of the amounts of water to be extracted are considered to be known. The relationship between quality 'raw' water and the costs of purification will be derived from data of the Governmental Institute for Drinking Water supply. Along the left side of the triangle there is an interaction between water extraction and agricultural income (e. g. damage to agricultural crops when extracting too much ground water for domestic supply, but also: extraction of ground water for sprinkling crops). In order to estimate the costs of water extraction the relationship between possibilities of exploration and geo-hydrological/ chemical conditions must be known. Also effects of exploration upon water management in the entire area must be quantified.

Values of nature - Here the reference value is that value that is potentially possible. By this definition nature sets limits to the conditions for agriculture and water extraction (arrows on bottom - and right hand side of triangle). It is very difficult to express the different values in terms of money. To characterize the values one often separates between classes of development with respect to changes in both water quantity and water quality. Therefore effects of the latter two on natural vegetation must be known. Also the influence of nature management on water management has to be evaluated.

The question now arises which of the already fysical models must be developed in order to describe the processes involved adequately. To answer this question in more detail we start with the well known hydrological cycle, depicted in Fig. 3.

There exists an exchange of moisture flows between the atmosphere and the unsaturated zone of the soil. Irrigation or rain water that is not intercepted by the crop will reach the soil. Part of it will become soil moisture only to be lost by soil evaporation or transpiration. The part of rainfall that does not infiltrate will be lost as surface runoff. The excess of soil moisture will percolate downward to the ground water table and recharge the ground water storage. Reversely water can be released from the saturated zone by the process of capillary use. Between the saturated zone and the surface water there exists a discharge to or a sub-irrigation from the open water courses, depending on the level in the latter. Finally

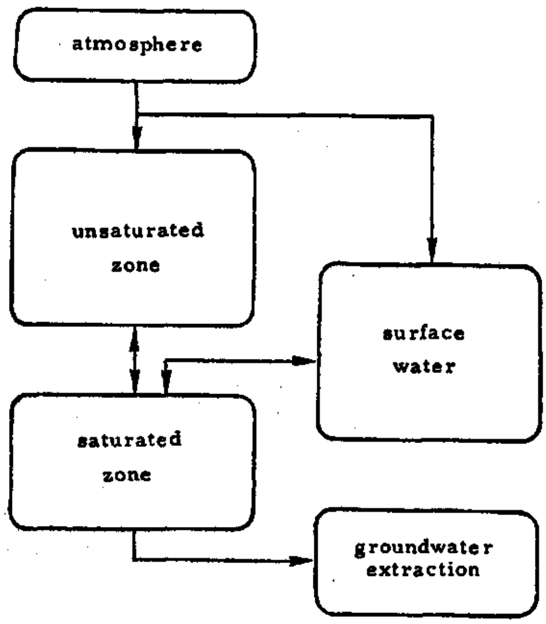

Fig. 3. Schematical representation of the hydrological cycle

water can be extracted from the saturated zone by pumping.

III. WATER QUANTITY

Following the hydrological cycle (fig. 3) we now come to the water quantity models that can describe this cycle (fig. 4).

Unsaturated zone - The model SWATR (Soil Water Actual Transpiration) of Feddes, Kowalik and Zaradny (1978) calculates on a daily basis the water balance terms of a soil under vegetation, i. e. transpiration, soil evaporation, infiltration, run-off, the fluxes through both, the bottom of the root zone and the bottom of the soil system and the change in soil moisture over the entire soil profile. Recentely a modified extended version SWATRE(xtended) has been developed by Belmans, Wesseling and Feddes (1981), where the number of possible boundary conditions at the bottom has been increased.

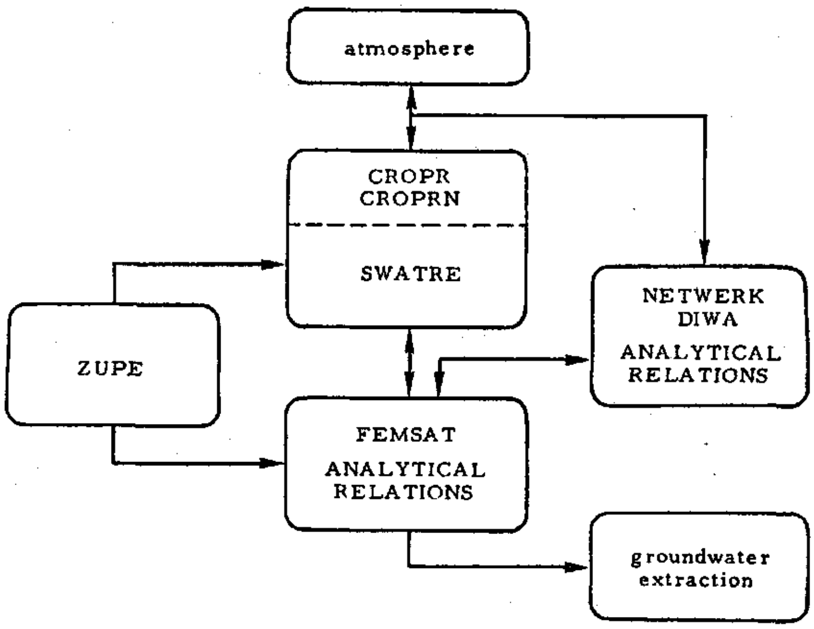

Fig. 4. Scheme of the water quantity models involved in the hydrological cycle

The model CROPR (Crop Production) calculates both the potential and the actual growth rates and dry matter yield of a crop under conditions of optimal fertilization. By means of SWATR and CROPR the relationship crop yield/water use can be established. In principle it is also possible to compute with SWATR the amount of moisture available for natural vegetation.

In order to determine the relationship crop yield/Nitrogen fertilization we consider to modify CROPR into CROPRN applying some functions of the nitrogen balance model of Rijtema (1980).

Saturated zone - The model FEMSAT (Finite Element Saturated) of Van Bakel (1978) schematizes ground water flow into a horizontal flow in aquifers and vertical flow in less permeable layers. For each time step the program calculates the water balance terms both for each model point of the regional network and for each layer.

The idea is to combine a simplified version of SWATRE with FEMSAT to some kind of a 3-dimensional model called ZUPE (Zuidelijke Peel).

For a description of the relationship between saturated zone/ surface water respectively saturated zone/ground water extraction we will make use of the well known relationship developed by Ernst (1978a and b).

Surface water - The model NETWERK of Van Doorne (1966) calculates the division of the amount of inlet water over the various open water courses being present in a certain area. An alternative model is DIWA (Dimensionering Waterlopen) as developed by Gelok (1976). The question can be raised if supply - and discharge waves of the surface water should be taken into account or not.

IV. WATER QUALITY

In fig. 5 the hydrological cycle with respect to water quality is depicted.

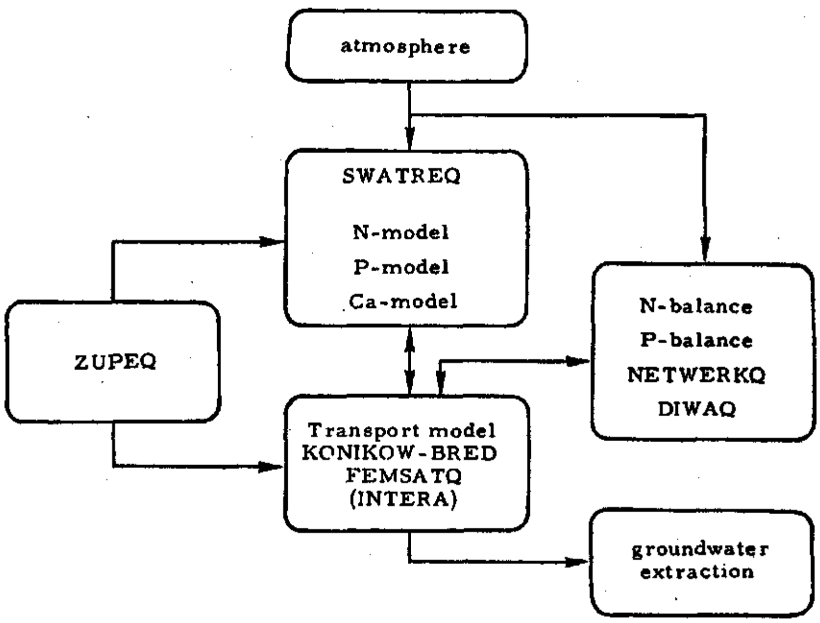

Fig. 5. Scheme of the water quality models involved in the hydrological cycle

Unsaturated zone - The model SWATRE could possibly be used as a basis for a SWATREQ(uality) model by which the N(itrogen), P(hosphate) and possibly the Ca(lcium) management could be simulated.

With the N-balance model of Rijtema (1980) effects of differences of farm management, improvement of local drainage, over dosing and dumping of animal manure upon nitrogen management of grass land covered soils can be simulated. For maize results have been reported by Verheijen en Steenvoorden (1981).

A one-dimensional P-balance model has been developed by Gerritse (1980) en Van Riemsdijk en De Haan (1980) by which processes of inter-action and accumulation can be simulated.

A first step to simulate the Ca-balance of the soil has been made by Rijtema (1981).

Remark: Simulation of N-, P- and Ca-balance occurs on a much larger time scale than the water quantity models. May be the outputs of SWATRE could be used as an input for simplified water quality models.

Saturated zone - The transport model of Hoeks (1981) could be used as a first approach to simulate the transport of solutes. This model is based on a point source. It contains a number of equations that describe ground water flow along stream lines in combination with equations describing processes of inter-action in the soil and bio-chemical decay. The model does not contain either dispersion or ion exchange.

The model KONIKOW-BREDEHOEFT (1978) is a ground water quality model imported from the USA by the Governmental Institute for Drinking Water Supply. It is based on the method of characteristics, i.e. a particle is followed on its transport direction. This 2-dimensional model (vertical or horizontal) is based on a diffusion type convection equation with linear adsorption and decay terms for one single component. The model is well documented. However, only one single component is taken into account, and interaction processes cannot be simulated.

The model INTERA is a 3-dimensional finite difference model, which at the moment seems to be too complicated to be used for practical field conditions.

As in fig. 4, for water quantity, we need to combine SWATREQ and FEMSATQ(uality) to a 3-dimensional ZUPEQ(uality).

Surface water - Again similarly to the scheme of fig. 5 models NETWERKQ(uality):DIWAQ(uality) need to be developed. May be it suffices to work with simple solute balance models on yearly basis.

V. MODELS FOR AGRICULTURE, NATURE AND WATER EXTRACTION

In fig. 6 are shown the basic input data into the models for agriculture, nature and water extraction. These are needed to calculate agricultural income, values of nature and costs of water extraction respectively.

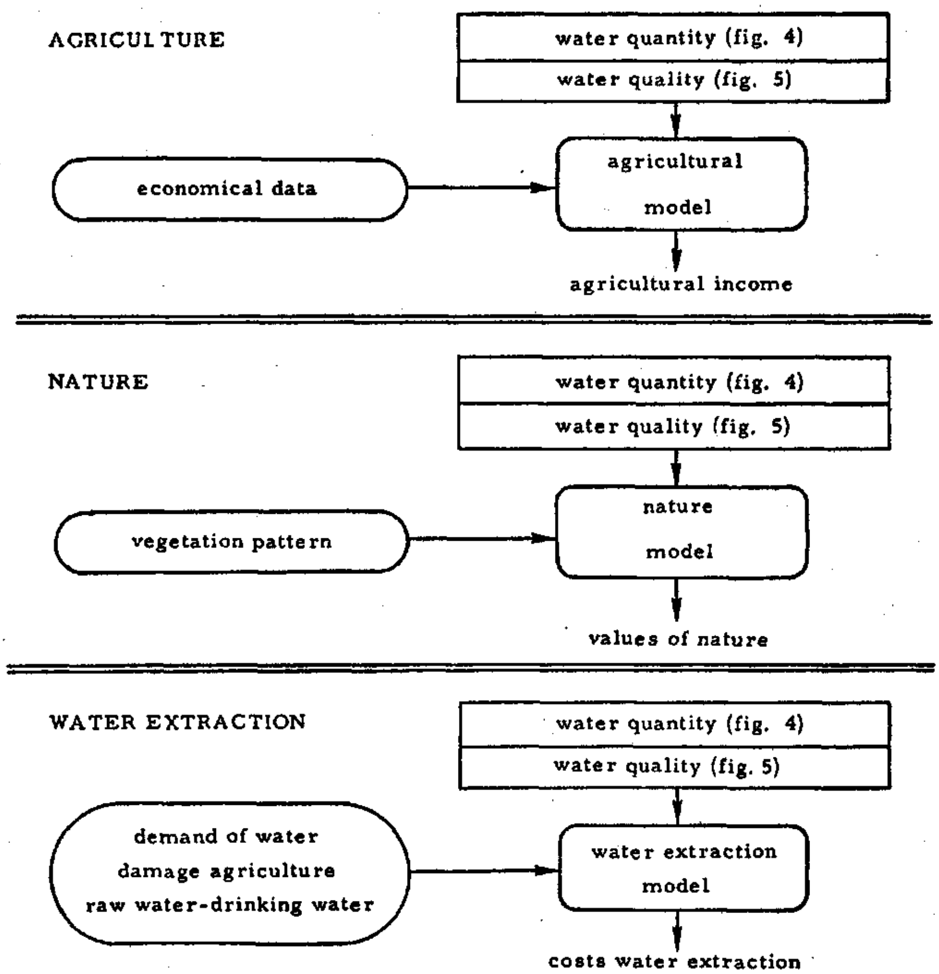

Fig. 6. Flow chart of the input data in the models for agriculture, nature and water extraction

Agriculture - The agricultural model is a simulation model. A submodel is AGREVAL (Agrarische Evaluatie Landinrichtingsplannen) as developed by Righolt and Reinds (1980). It computes by the method of linear programming the costs of tillage, size of economic production and labour income of a simple farm.

The simulation model contains parts of the so-called 'Growth' model of Filius (1979). The model simulates long term developments of individual farms and contains functions for production income, labour mobility, for savings and investments and for allocation of farm land.

Applying the relationships crop yield/water use and crop yield/fertilization as obtained from the water quantity and quality models, productions of standard farm holdings (i. e. 'standard' with respect to conditions of management) are computed by AGREVAL. Computations are carried out for single management strategies, i. e. for well defined conditions of water management and fertilization. After that a number of corrections of the production of the 'standard' farm are being made in order to reach 'actual' productions. The corrections concern such factors as farm size, parcellation condition, availability of labour and capital, quality of management, etc. Also weather conditions and production plan are taken into account. When the 'actual' productions have been calculated, the development of income over the years is being computed with a modified 'Growth' model.

Nature - The nature model consists basically of the relationship between values of nature and the present environment as far as water quantity and quality are concerned. The values will be split up in a number of classes on the basis, both of literature studies and vegetation pattern studies in some selected areas.

The hydrological environment will be characterized by the variation and absolute values of the ground water level, available soil moisture and the aeration condition of the soil. The water quality environment by the nitrogen and phosphate condition of the soil and by the cation (Ca, Mg, K, Na) condition of the ground water.

Introducing the vegetation pattern and the mentioned environmental characteristics in the nature model as reported by Kemmers

(1980) and Both and Van Wirdum (1979) one is able to determine a certain value of nature for each separate management strategy.

Water extraction - The water extraction model is only the conversion of extraction of amounts of water of certain quality into costs of water extraction.

As input in this model we consider first a given demand of water of certain quality. Secondly the damage to be paid to the farmers because of draw down of the freatic surface by the extraction. Thirdly the costs to be made to convert 'raw' water into drinking water (e. g. the costs made by reducing the nitrate content of the 'raw' water).

With the models ZUPE and ZUPEQ the amounts of water that can be extracted both in a technical and economical way, can then finally be computed.

VI. OPTIMIZATION MODEL

The output of the models for agriculture, nature and water extraction serve as an input for the so-called optimization model(fig. 7).

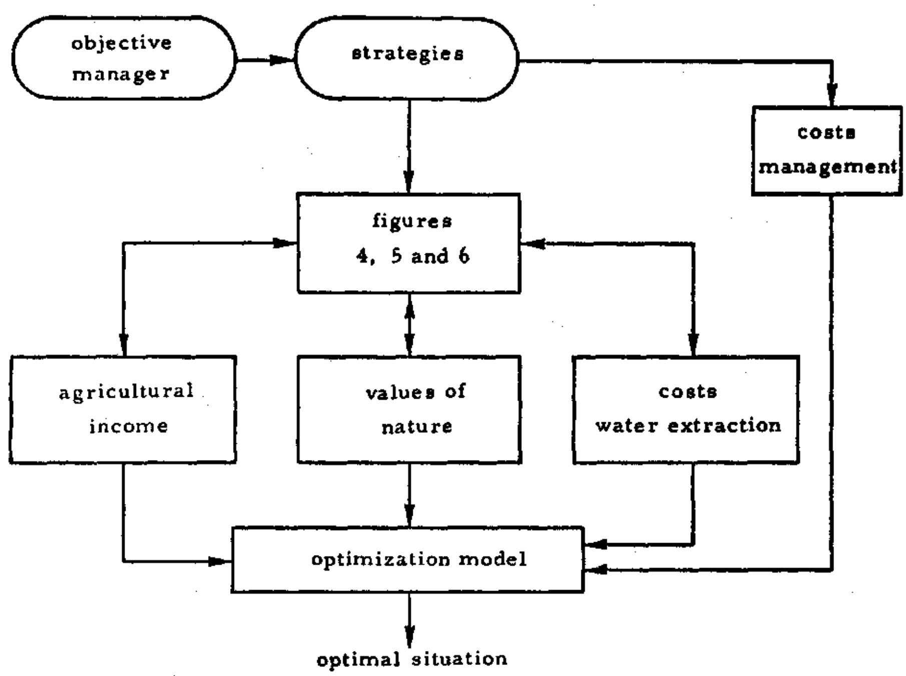

Fig. 7. Schematics representation of the optimization procedure following one strategie

For any given objective of the manager a well defined predetermined strategy can be followed with respect to investments, conditions for water management, fertilization, etc. With the models discussed before, the consequences of any strategy for agricultural income, values of nature and costs of water extraction can be estimated. For each single strategy the three categories can be varied (see feed back arrows in fig. 7). The optimization model now tries to select the optimal situation. During the selection procedure one aims at a maximization of agricultural income, at maintaining the value of nature as high as possible and the costs of water extraction as low as possible.

The difficulty in the optimization procedure is that the values of nature can hardly be expressed in monetary terms. Therefore it is difficult to compare this category with the other two. Hence the manager has to set weights himself in order to make the three categories comparable.

Remark: The entire approach consists of a number of different sub-models of which the output of one model serves as an input for another model. The question arises if from a system analytical point of view this approach is feasable or not.

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