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EFFECTS OF FRESH-WATERSUPPLY OF SCHOUWEN-DUIVELAND, THE NETHERLANDS

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Abstract

Upon completion of the Delta Works, parts of the Rhine estuary will become stagnant basins. Desalination of these basins create possibilities for additional water-supply to adjacent agricultural areas. The study, presented in this paper, was intended to provide arguments for the decision upon desalination of one of the basins: Lake Grevelingen. It evaluates the agricultural effects for one of the islands: Schouwen Duiveland of water-supply from either Lake Grevelingen or, in case of a saline Lake Grevelingen, from the nearby Volkerak. (Figure 1).
The paper treats three major aspects. The conclusions are:

- the increase of crop yield by additional water supply amounts to over 15% for potatoes, fruit trees and grass, between 10% and 15% for sugar beets, cereals, leguminous plants, onions, celeriac and bulbs; and less then 5% for chicory, winter carrots and leek.
- the maximum water demand for sprinkling and flushing amounts to 3.4 $mm.day^{-1}$. If areas with a strong saline seepage are excluded from flushing the demand decreases to 2.5 $mm.day^{-1}$.
- realization of a fresh-watersupplysystem requires an investment of about Dfl $20*10^6$. The extra investment in the case of a saline Lake Grevelingen amounts to 10% of the total investment. The net yearly profit of fresh-water supply amounts to between Dfl $3*10^6$ and Dfl $4*10^6$.

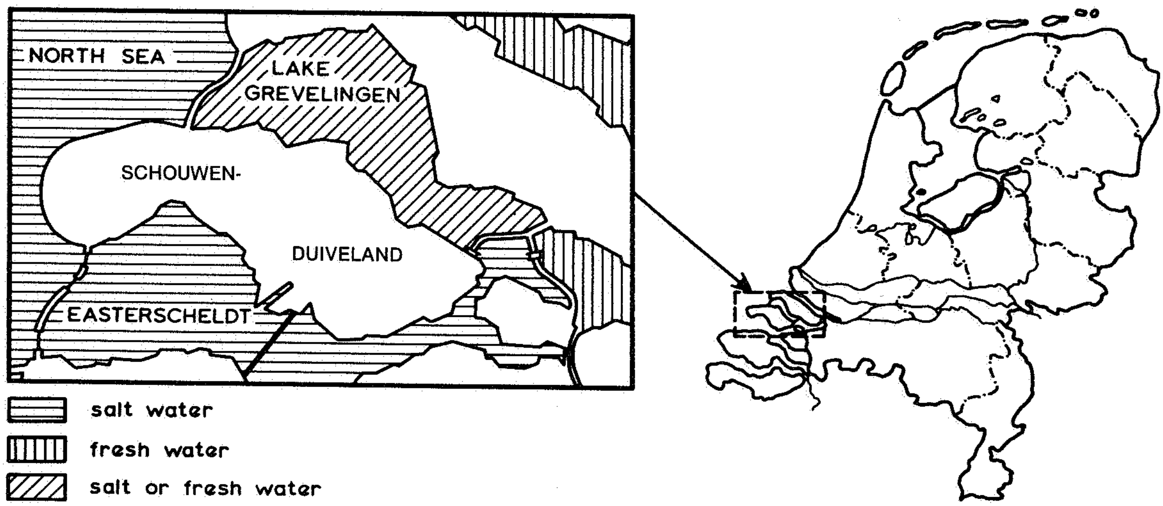


Figure 1. Location of study area

1 Increase of crop yield by fresh-watersupply

The crops on Schouwen Duiveland often suffer from an insufficient water supply. The reduction in yield corresponds with the magnitude of the occuring water deficiency. In this study the water deficiency has been determined as the difference between actual- and potential evapotranspiration. The actual evapotranspiration depends on meteorological conditions, crop type and soil characteristics. In order to account for variations in crop- and soil type Schouwen Duiveland was divided into square elements with an area of 25 ha. For each element a representative crop- and soil type was determined and the actual evapotranspiration was computed using historical data of meteorological conditions.

1.1 Method for calculation of actual evapotranspiration

Rijtema (1965) and De Laat (1980) presented a calculation scheme in which the transient vertical flow in a soil column is simulated by a

succession of steady state situations with a duration of 10 days. In the scheme the soil column is divided into a root zone, an unsaturated- and a saturated subsoil.
The rootzone is defined as the layer in which the crop withdraws the water. Because of the predominant influence of the water uptake by the crop on the flow, the presence of hydraulic gradients in the root zone is ignored in the scheme. Furthermore, water uptake by the crop equals potential evapotranspiration if the soil water pressure is higher than a certain critical value and equals zero if the soil water pressure is lower than -1600 kPa (pF 4,2). For values of the soil water pressure in the intermediate range the actual evapotranspiration is obtained by interpolation using a semi-logarithmic relation.
In the unsaturated subsoil only flow in the vertical direction is considered. Water storage is taken into account.
The saturated subsoil represents the upper part of the groundwater storage which can be fed and depleted by exchange with deep aquifers and the surface water system.
To execute such a simulation it is necessary to have data on the inital soil water content, the physical properties of the different layers in the soil and the fluxes through the upper and lower boundaries of the soil.

1.2 Data

Data were available on the free water evaporation and the precipitation in the study area during the summers (April-September) of the years 1933-1980. The potential evapotranspiration E_p for the different crop types in the summers mentioned has been derived from the free water evaporation E_0 using the formula $E_p=f.E_0$. Values for the crop factor f were taken from the literature.
From existing maps a representative crop type could be determined for each of the elements. The crop types distinguished are: potatoes, sugar beets, cereals, leguminous plants, onions, chicory, winter carrots, celeriac, leek, bulbs, fruit trees and grass. The total area of these crops amounts to about 15,000 ha. For each crop type the thickness of

the root system and the critical soil water pressure were used as input data.
Similary a representative soil type was determined for each element. The many different soil types on the soil map have been grouped to 11 units with corresponding physical properties. The relationships between the soil water pressure and the soil water content, and between the soil water pressure and the hydraulic conductivity were determined for each layer in the 11 units.
The flow between the saturated subsoil and the surface water system was simulated by a drainage function. The soils on Schouwen Duiveland are drained by pipes, situated at 0.9 m below surface. The discharge through the drains has been supposed to be proportional to the average depth of the groundwater table below the land surface; with a discharge equal to zero at a groundwater depth of 0.9 m and equal to 8 $mm.d^{-1}$ at a groundwater depth of 0.3 m. Infiltration of surface water through the drains will not occur because the drains are situated above the surface water-level. Direct drainage of infiltration from the surface water has been ignored because of the great distance between the ditches and the low transmissivity of the soil.
The flow between the shallow deep groundwater could be derived from the results of a geohydrological study.
The initial soil water content has been derived from the situation found in the field at the beginning of the summer; this means a groundwater depth equal to the average spring groundwater depth and an equilibrium moisture profile in the unsaturated zone.

1.3 Results

For each element the actual evapotranspiration for the summers 1933-1980 was calculated and compared with the potential evapotranspiration of the crop. The water deficiencies were averaged for the crop types distinguished over the different elements. Then for each crop the water deficiency was averaged over the 47 years. Expressed in percentage of average potential evapotranspiration the deficiency for the different crops amount to: potatoes 18%, sugar beets 10%, cereals 10%, leguminous

plants 15%, onions 12%, chicory 4%, winter carrots 3%, celeriac 13%, leek 2%, bulbs 10%, fruit trees 20% and grass 16%.
To transform the thus found water deficiency into a reduction in yield it was assumed that the interrelation between crop yield and actual evapotranspiration can be approximated by a linear function. If it is furthermore assumed that the application of sprinkling will reduce the water deficiency and the yield depression to zero, the presented percentages for water deficiency also indicate the increase of crop yield by additional water supply.

2 Water demand for sprinkling and flushing

Due to the continuous inflow of salt groundwater from the sea the surface-waters have become brackish. They will remain so when fresh water is supplied unless an extra amount of water is added for flushing.

2.1 Salt load on surface waters

Depending on the hydrological circumstances the chlorinity load may vary strongly in space and in time. In order to compute the amount of fresh water needed for flushing, a simulation model of the chlorinity load was prepared in two stages. In the first stage the areal distribution of the seepage was computed for stationary flow, using a finite element model. The second stage was devoted to the modelling of the temporal fluctuations of the salt load.

2.1.1 Areal distribution of seepage

The computation of the areal distribution of seepage was done with a standard computerprogram of the Delft Hydraulics Laboratory, GROMULA. (Broks and Dijkstra 1979). GROMULA is a Galerkin finite element program for flow in a multi layered system of aquifers. Figure 2 gives an impression of the element grid that was used for Schouwen Duiveland. The

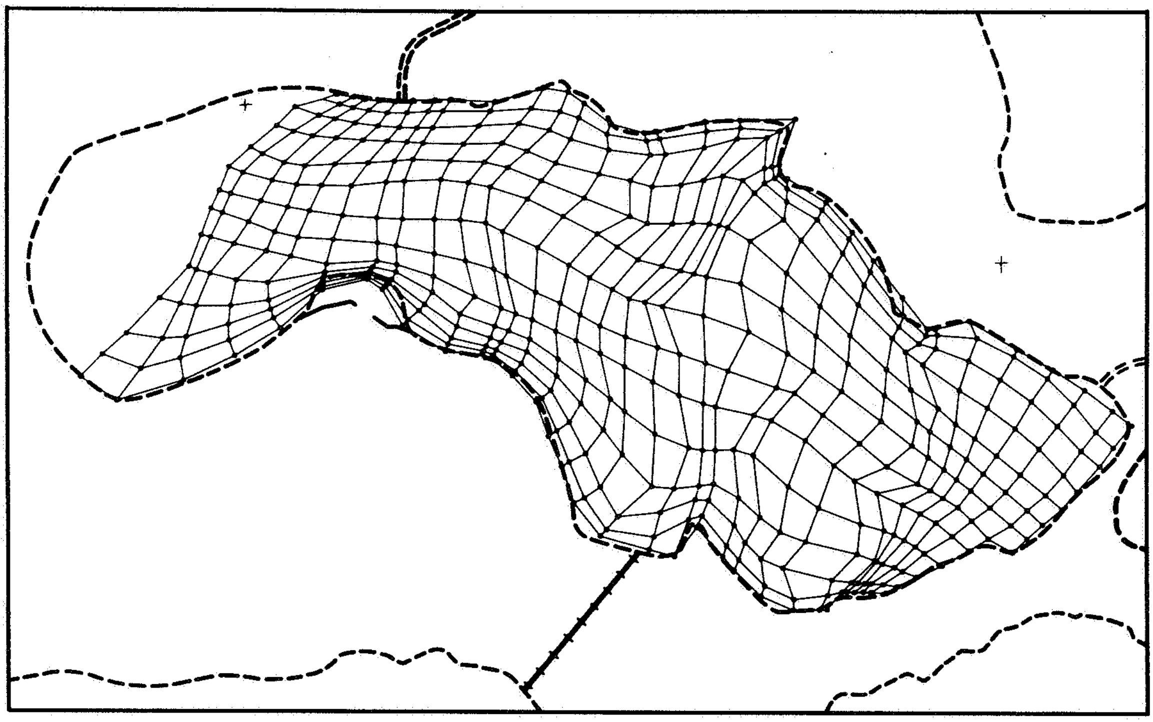


Figure 2. Element grid, Schouwen Duiveland

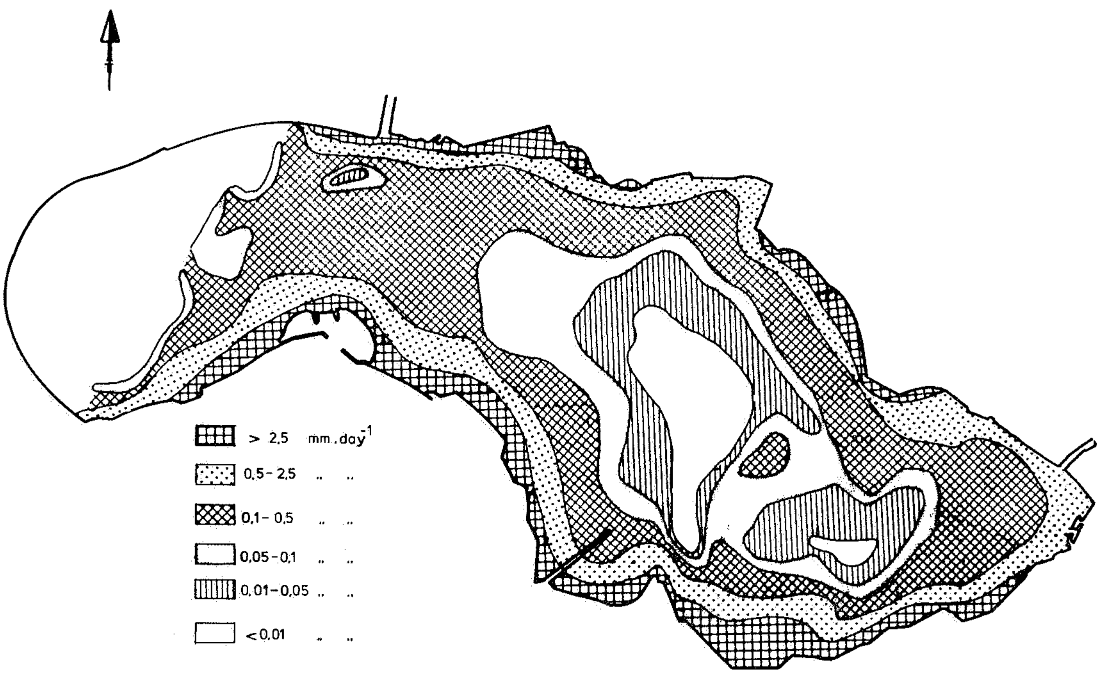


Figure 3. Computed areal distribution of seepage

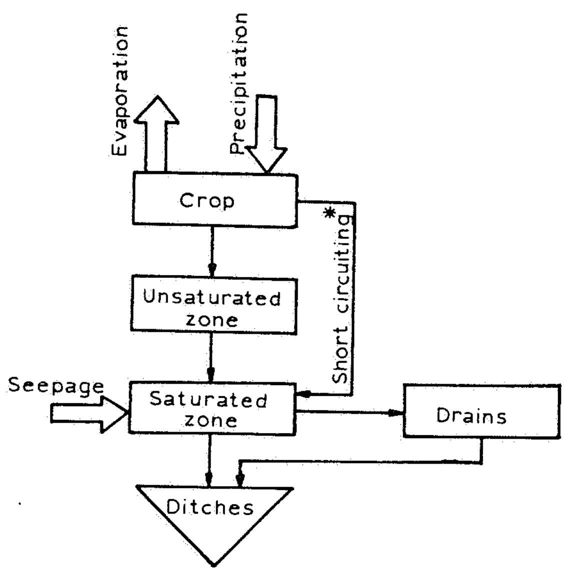
geohydrological scheme consists of two aquifers divided by a semi-pervious layer. On top there is also a semi-pervious layer, in which a constant polderlevel is maintained by means of surface water ditches. The boundary conditions consist of a constant waterlevel (mean sea level) along the boundary of the grid and a constant polderlevel in the upper semi-pervious layer.
Observed piezometric levels, available for both aquifers were used for model calibration. Moreover, the computational results could be verified against existing water balances over several years, available for the greater part of the isle. With the calibrated model the areal distribution of the stationary seepage was computed for a future situation. when ditch-levels may be adapted to decrease seepage. Figure 3 shows the computed seepage to the top layer.

2.1.2 Temporal fluctuations of the salt load

Whereas the inflow of salt groundwater from the sea is more or less stationary the exfiltration to the surface waters shows marked fluctuations in time. This phenomenon is attributed to the storage of salt groundwater in the semi-pervious toplayer during summer. There appears to exist a close relation between the fluctuations of the salt discharge and the effective precipitation. In order to formulate this relationship the computer program LINMOD has been develloped and applied to each element of the GROMULA model. Essentially LINMOD describes the discharge of water from the landsurface to the ditches through the saturated zone. As the problem doesn't require comprehensive knowledge of the processes in the plant-soil system both the crop and the unsaturated zone are modeled very schematically.
Figure 4 shows the lay-out of LINMOD. From field observation it was concluded that after each shower some rapid downward flow takes place, presumably through cracks. In the scheme this effect is indicated as "short circuiting". Discharge may take place either through the drains or through the subsoil. In both cases the relation between inflow and outflow of the saturated zone can be expressed in the form

$$F_{out}(t) = \int_{o}^{t} \alpha F_{in}(t-\tau).e^{-\alpha\tau} d\tau$$

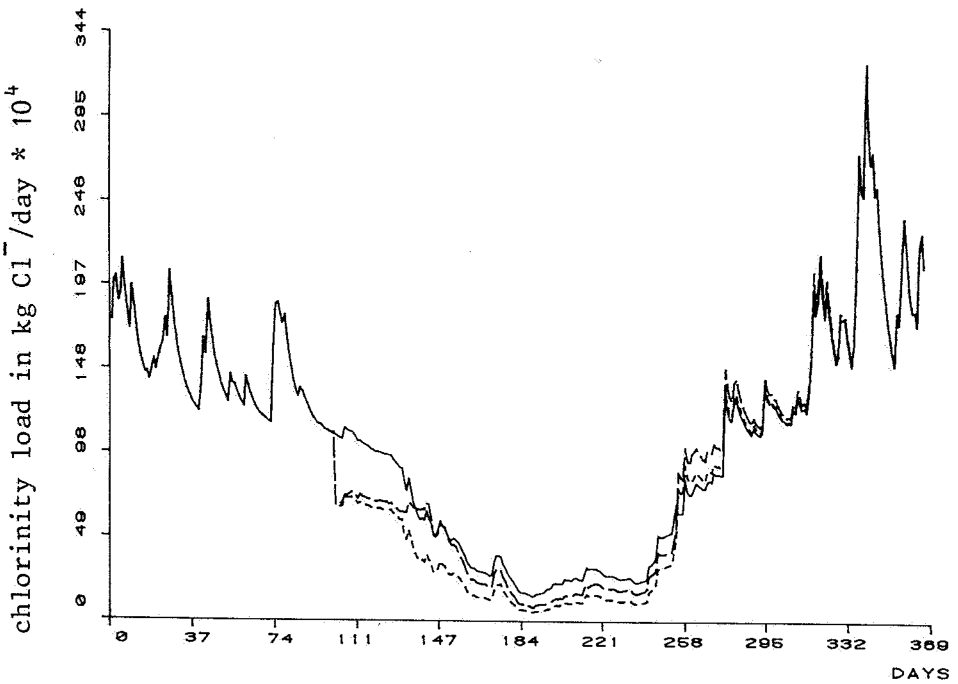
where α (reaction factor) takes on different values each time the phreatic level passes the drains.
To transform discharges to salt loads the drainwater-runoff is multiplied by the chloride content of the drainwater while the runoff from the subsoil is multiplied by the chloride content of the upper aquifer. For both parameters maps where available from earlier investigations.



* short circuiting:rapid downward flow of water through cracks

Figure 4. Lay-out of the computer program LINMOD

The model LINMOD has been calibrated for a sequence of years. Figures 5 and 6 show examples of the computational results. Figure 5 shows the time dependent chloride charge (summed over the area of investigation). The influence of certain watermanagerial measures is clearly seen: when the polderlevels are raised during the summer the discharge of salt decreases. The effect is partly conceled when sprinkling is applied. Figure 6 shows the calculated spatial distribution of the salt load at the start of the growing season of 1976.



—— chlorinity load (present polderlevels)
--- chlorinity load (raised polderlevels)
— — chlorinity load (raised polderlevels and sprinkling)

Figure 5. Computed temporal distribution of the chlorinity load (1976)

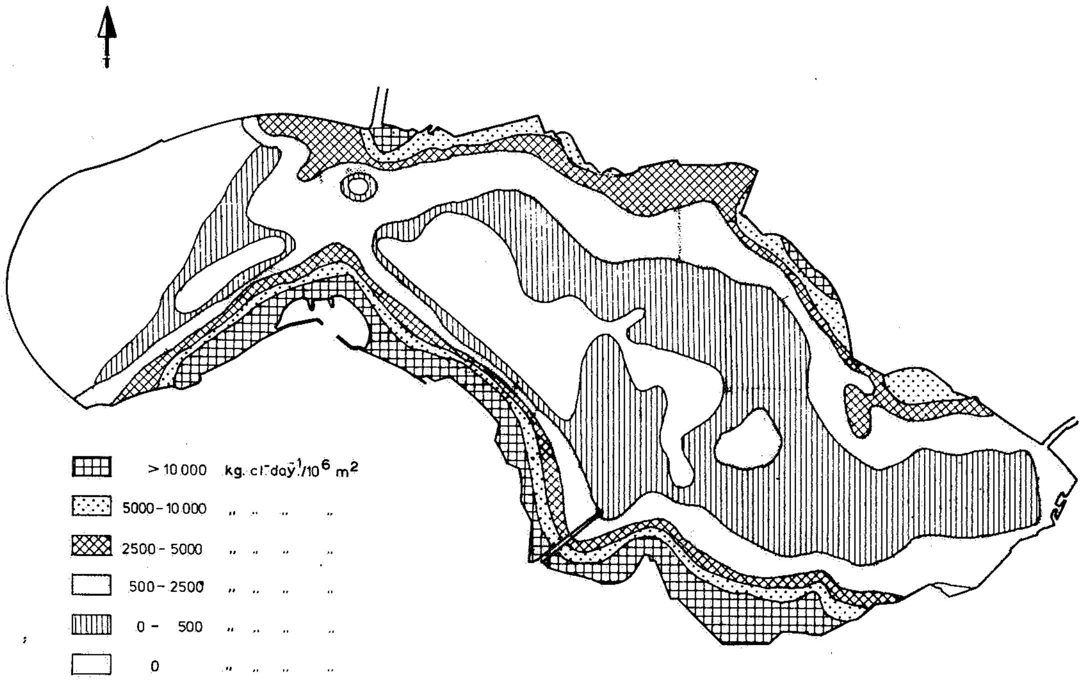


Figure 6. Computed spatial distribution of the chlorinity load (april/may 1976)

2.2 Demand of water for flushing

The most critical period of flushing appears to occur at the beginning of the growing season. Once the salt load at this time is known, the demand of water for flushing can be calculated in a relatively simple way. The calculation is based on the principle that irrigation takes place from side branches of the system and the optimal situation is reached when the required quality standard is just met at the confluence of the side branches and the collector branches. As the water needed for sprinkling also helps to combat salination, no discrimination is made between water for sprinkling and flushing.
The calculation is done for two different supply systems. One with a diffuse intake from the fresh Lake Grevelingen and the other with a concentrated intake for supply by pipe line.
In the most critical periods the following results are obtained: for both systems the amount of water needed for flushing and sprinkling is 3.4 $mm.day^{-1}$ of which 1 $mm.day^{-1}$ is used for sprinkling. When some very saline areas are excluded from flushing this amount may be lowered to 2.5 $mm.day^{-1}$. Compared to other coastal areas of the Netherlands the calculated amount of water needed for flushing is extremely high. However, the salination of Schouwen Duiveland is known to be extraordinary severe.

3 Investments and economic effects

3.1 Investments

The investments required for the realisation of a fresh water supply system mainly result from groundwork and constructions. For the main alternative in case of a fresh lake the investments amount to Dfl 22.3 $* 10^6$ which may be lowered to Dfl 18.4 $* 10^6$ by the exclusion of some very saline areas. The main alternative for a salt lake requires Dfl 24.3 $* 10^6$ which reduces to Dfl 20.0 $* 10^6$ when very saline areas are excluded (the pipeline needed to transport fresh water to the island, is not included in these figures). It can be concluded from these figures that the salt variant always requires a higher investment.

3.2 Economic effects

The economic effects (net yield) for the farmers on Schouwen-Duiveland are, as far as the agriculture and horticulture are concerned (90% of the cultivated land) accounted by an optimization model developed by the Research Station for Arable Farming and Field Production of Vegetables in Lelystad. The economic effects on fruit culture, stock farming and bulb culture, the remaining 10% of the cultivated land, are estimated in a different way.
For the computation four scenario's are considered:
PS- : Present situation without sprinkling
PS+ : Present situation with sprinkling
OPT- : Optimum situation without sprinkling
OPT+ : Optimum situation with sprinkling
The farm-plans for the two OPT scenarios are obtained from the optimization model, with the maximum net profit as an optimization criterion and farm size, labour force, tool cost, demands of crop rotation, yield reductions and crop prices as input data.
In order to quantify the effects of changes in the farm-plan due to fresh water supply the model is applied on farm-level. The cost of sprinkling, composed of fixed anual- and variable cost is input to the model. The capacity of the sprinkling installation is put at 30- or 60 $m^3.hour^{-1}$, and the annual cost at 20% of the replacement value. This 20% consists of interest, writing-off, maintenance and insurance. The variable cost, mainly cost of energy depend on the gross water gift, the capacity of the installation, the price of gas-oil and the sprinkled area. The accounted total sprinkling costs vary from 467-691 Dfl/ha, equally composed of fixed - and variable cost. From these figures and by comparison of actual and potential crop yield it can be concluded that sprinkling appears to be profitable for potatoes, onions, celeriac, sugar beets and chicory.
Table 1 shows the area used for agriculture and horticulture under the different scenarios as computed by the optimization model.

Table 1. Area used for agriculture and horticulture (in %)

scenario	PS- and PS+	OPT-	OPT+
agriculture	89	72	68
horticulture	11	28	32
Total	100	100	100

The shift in land use under the two OPT scenarios is obvious. Though on a national scale the indicated increase in horticultural area is not very likely, it is conceivable on a regional scale. Table 2 presents the net farm economic effects from sprinkling. The minimum effect is derived from comparison of the two PS scenarios, the maximum effect from comparison of the two OPT scenarios.

Table 2. Net-farm economic effects on Schouwen-Duiveland (in million guilders)

	minimum effect	maximum effect
Agri- and horticulture	2.50	3.10
Fruit culture	0.60	0.60
Stock farming	0.15	0.15
Bulb culture	0.01	0.10
Total	3.26	3.95

The presented minimum effect for agri- and horticulture of Dfl $2.5 * 10^6$ corresponds with an increased net yield of Dfl 4100.- for a 20 ha farm and Dfl 9800.- for a 40 ha farm.
The gross effect of sprinkling is obtained by addition of the sprinkling cost, which amounts to about Dfl $3.6 * 10^6$, to the presented net effect. Thus the gross minimum effect of sprinkling amounts to Dfl $6.9 * 10^6$ and the gross maximum effect to Dfl $7.6 * 10^6$.
The real economic effect will be higher than indicated by these figures, due to the so-called multiplier effect which has not been taken into account. Though introduction of sprinkling will lead to intensivation

of the agriculture, the creation of extra employment is hardly to be expected, because of the occurence of idle time in the present situation.

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