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THE NITRATE CONFLICT BETWEEN MUNICIPAL WATER SUPPLY AND AGRICULTURE

THE NIMWAG MODEL

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1. INTRODUCTION

This description of the NIMWAG model has the same sequence as the computerprogram. Annex 1 gives the structure diagram of the main computerprogram.
The NIMWAG model calculates NO3-N concentrations in the water extracted by a deep well. The model has been made operationel to execute calculations for 166 extraction areas. For each extraction area calculations have been made for 16 different fertilization alternatives.
The model can be divided into three parts: a part with hydrological calculations, a part with fertilization calculations and a part to calculate the NO3-N concentrations.
The hydrological part is explained in the chapters 4 and 5 and calculates the spread of the feed in the extraction area and the residence times of the infiltrating precipitation excess. In the aquifer the flow towards the well is regarded as convergent radial flow (figure 1).

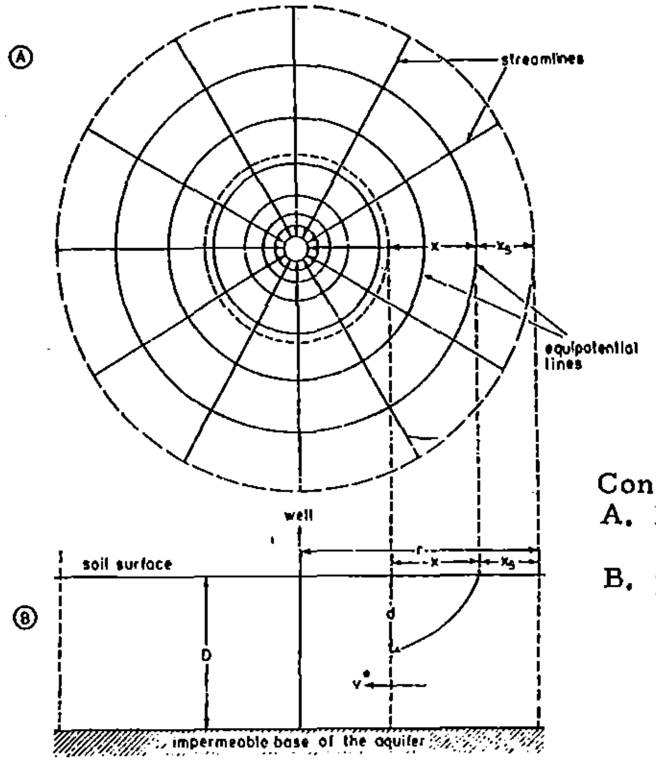


Fig. 1.

Convergent radial flow in an aquifer
A. horizontal view with equipotential lines and streamlines
B. path of a streamline in the aquifer

The calculations about the fertilization level are explained in the chapters 6 and 7. The fertilization level is calculated in dependence to the landuse in the extraction area and to the chosen fertilization alternative.
The chapters 8 and 9 explain the calculations of NO3-N loads in the groundwater caused by the inflow of nitrate into the saturated zone and the denitrification in the saturated zone.

The computer-program is written in VAX-11 FORTRAN on a VAX-computer with a VMS operating system. All the variables used in the computer-program are formed by combining letters and combinations of letters. Annex 2 gives a list of these letters and combinations of letters.

2. THE DATA-INPUT

Data enter the model in the main program and in a subroutine (INPUT).

2.1. the main program

A special file has been created with general data about the extraction areas. This file is being read in the main program and contains the variables given in annex 3.

The main program contains the possibility to enter data about the manure quantities that are exported and imported in the extraction areas. These data were not available so they have been set to zero. Data about the pH-factor of the three layers (top layer, semi-pervious and aquifer) also were not available and have been set to 6.

2.2. the subroutine INPUT

In this subroutine data enter the model from three files, containing data collected by the LD (Landinrichtingsdienst,afdeling Grondwaterbeheer), LEI (Landbouw Economisch Instituut) and STIBOKA (Stichting voor Bodemkartering).
The data mainly originating from the LD (CATTENSTART, 1983) are presented in annex 4a; where necessary these data have been supplied with data collected by the ICW.
The LEI (LUESINK, WIJNANDS, 1985) supplied data about manure production and manure excesses on base of data about the community in which the pumping station is situated. The manure excess has been calculated by the LEI for 12 options of fertilizer application. Annex 4b shows the data calculated and given by the LEI.
The STIBOKA has collected data about the average highest groundwatertable. They have been collected before the size of the extraction area was known and therefore it was assumed that the extraction areas had the shape of a circle and had a surface of 6 m2 per m3 waterextraction per year. This is an estimation of the surface of the area with a reduction of the groundwatertable caused by the extraction of 0.05 m or more (RIJTEMA,1982). Annex 4c gives data as they enter the model and which are mainly based on information from the STIBOKA.
In the model eleven types of landuse are distinguished in the extraction areas:

1. grassland with management agreement,
2. intensively used grassland, limited grazing,
3. intensively used grassland, unlimited grazing,
4. arable land with a crop rotation of cereals, cereals, potatoes and beets,
5. continuously foddermaize, with heavily dumping of slurry
6. continuously foddermaize, with some dumping of slurry,
7. horticulture,
8. municipal area,
9. forestland,
10. non-fertilized natural land and
11. land across bigger rivers, in fact infiltration of river water.

Data from the LEI have been used to make a division of the types of landuse. The landuses 1, 2, 10 and 11 are not used in the model, because there were no data available.

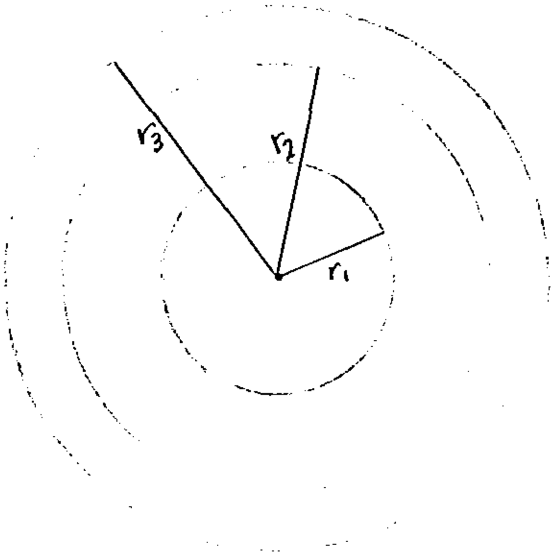
For the 12 options of manure-excesses given by the LEI a fraction of the total amount of required manure is calculated indicating the effective organic nitrogen fraction (or: the artificial fertilizer equivalent) in the applied quantity of manure.
16 different alternatives for fertilization restrictions are determined for dumping of manure, application time and total fertilization level. Table 1 gives the determined restrictions.

Table 1. The determined fertilization alternatives.

fertilization alternative	protection area	outer-area
0	no restrictions	no restrictions
1	no overdosing	no restrictions
2	spring-application	no restrictions
3	75% of requirement	no restrictions
4	50% of requirement	no restrictions
5	no overdosing	no overdosing
6	spring application	no overdosing
7	75% of requirement	no overdosing
8	50% of requirement	no overdosing
9	no manure	no overdosing
10	spring application	spring application
11	75% of requirement	spring application
12	50% of requirement	spring application
13	75% of requirement	75% of requirement
14	50% of requirement	75% of requirement
15	50% of requirement	50% of requirement

3. THE AREA-DIVISION (BLOC AREA)

The surface of the extraction area is determined by the area which carries of the main part of the precipitation excess (by default 95% has been chosen). By taking a smaller radius the extraction area is devided into three parts.
To protect the drinkingwater-supply on a long term a residence time of 100 years has been chosen to indicate the boundary of the protection-area. The possible influence of atmosferic deposition caused the introduction of a so-called outer-area. In the hydrological part of this model there is being calculated with an area surrounding the well where the ditches are dry.
Figure 1 shows the different areas around a deep well that are being used in this model.



- • = deep well
- r_1 = radius of area where the ditches are dry
- r_2 = radius of the protection area
- r_3 = radius of the extraction area
- $r_3 - r_2$ = ring which represents the outer-area

<u>Figure 2.</u> horizontal view of an extraction area
Schematization of the ....

Furthermore the circle of the extraction area has been divided into a number of rings. Every ring on its turn has been divided into parts indicating different types of landuse.

4. THE HYDROLOGICAL APPROACH (BLOC HYDRO)

In this part of the model hydrological calculations are made about the steady state situation which will exist when the pumping station has been working for a period in a region without regional groundwater flow on basis of a publication of ERNST (1971). The model can be used for the hydrological situations with the following subsequence of layers from top to bottom:

1. pervious, semi-pervious, pervious, impervious,
2. pervious, impervious and
3. semi-pervious, pervious, impervious.

The model calculates subsequently the drop of the hydraulic head in the pervious layer(s), the residence time of the water as a function of the place of infiltration, the flow pattern and the groundwater feed as a function of the place of infiltration.

Where the ground surface has only relatively small differences in elevation and the transmissivity of the underground layers is not very small, the excess precipitation is mainly carried off by groundwater flow to a system of rather closely spaced surface drains. Each groundwater extraction from thick phreatic or semi-confined aquifers results in a decline of the phreatic level. The pattern of drawdown of the phreatic level in the eastern and southern Pleistocene sands in the Netherlands depends on the presence of different types of drainage systems. Near the centre of the catchment area of the well the drainage system does not function anymore, whereas at greater distances from the centre the drainage system still operates.

ERNST (1971) gives a solution for the calculation of the mean decline of the pressure head in the aquifer containing the deepwell, as well as the calculation of the approximated decline of the phreatic level, both in relation to the distance from the deepwell. The following relations have been used in the present model:

-For the area where the drainage channels are not operating anymore (r<r1):

$$\varphi(r) = \frac{-\tilde{N}^{+}(r_1^2 - r^2)}{4kH} - \frac{Q_w}{2\pi kH} \ln\left(\frac{r}{r_1}\right) + \tilde{N}^{+}(\Lambda + \gamma_e) \qquad (1)$$

$$h(r) = \varphi(r) + \tilde{N}^{+}\Lambda \qquad (2)$$

-For the area where the drainage channels contain water (r>r1):

$$\varphi(r) = \tilde{N}^{+}(\Lambda + \gamma_e) \frac{K_0(r/C)}{K_1(r_1/C)} \qquad (3)$$

$$h(r) = \frac{\gamma_e}{\gamma_e + \Lambda} \varphi(r) \qquad (4)$$

-The unknown radius r1 can be determined by the expression:

$$\frac{Q_w}{\pi C^2 \tilde{N}^{+}} = \frac{r_1}{C} \left\{ \frac{r_1}{C} + 2 \cdot \frac{K_1(r_1/C)}{K_0(r_1/C)} \right\} \qquad (5)$$

Table 2 gives a list of symbols used in these equations and in the model.

As equation (5) is not allowing for a simple explicit expression giving X = r_1/C_0 as a function of the independent variable Y = $Q_w/\pi . C_0^2 . \tilde{N}^+$ a table has been calculated giving the relation: Y = X*(X + 2*K1(X)/K0(X)). (6) From this table the real value of X can be approximated by linear interpolation between Y1 and Y2. A similar procedure can be followed in the other calculations using tables of modified Bessel functions of the second kind. It should be remembered that $h(r)$ and $\varphi(r)$ are the depression cones relative to the original situation. This also holds for the fluxes when derived from the preceding equations. The horizontal flow intensity in the main aquifer can be found by differentiation of the equations (1) and (3) because:

$$Q(r) = 2\pi kHr \frac{d\varphi}{dr} \qquad (7)$$

So:

$$Q(r) = Q_w - \pi r^2 \tilde{N}^+ \qquad (r<r1) \qquad (8)$$

and:

$$Q(r) = 2\pi . \tilde{N}^+ . C_0 . r . \frac{K_1(r/C_0)}{K_0(r_1/C_0)} \qquad (r>r1) \qquad (9)$$

The residence time of the infiltrating water in the soil from the point of infiltration to the extraction point can be given by the following set of equations:

- r<r1:

$$T_{aq}(r) = \frac{-\varepsilon_{aq} H_{aq}}{\tilde{N}^+} \ln\left(\frac{Q(r)}{Q_w}\right) \qquad (10)$$

$$T_{se}(r) = \frac{\varepsilon_{se} H_{se}}{\tilde{N}^+} \qquad (11)$$

$$T_{top}(r) = \frac{\varepsilon_{top} H_{top}}{\tilde{N}^+} \qquad (12)$$

- r>r1:

$$T_{aq}(r) = \frac{\varepsilon_{aq} . H_{aq}}{\tilde{N}^+} . K_0(r_1/C_0) \int_r^{r_1} \frac{1}{K_1(r/C_0)} dr \qquad (13)$$

$$T_{se}(r) = \frac{\varepsilon_{se} . H_{se}}{\tilde{N}^+} . \frac{K_0(r_1/C_0)}{K_0(r/C_0)} \qquad (14)$$

$$T_{top}(r) = \frac{\varepsilon_{top} . H_{top}}{\tilde{N}^+} . \frac{K_0(r_1/C_0)}{K_0(r/C_0)} \qquad (15)$$

The flow pattern is determined by the depth of the streamlines at a certain distance from the point of infiltration and the residence time of the infiltrated water when it has arrived at a certain distance from the point of infiltration.

Table 2. list of symbols

txt	model	description	unities
$\varphi(r)$ =	POTAQ(DI)	= hydraulic head in main aquifer (related to the soil surface)	(m)
$h(r)$ =	POTTOP(DI)	= phreatic level (related to the soil surface)	(m)
Q_w =	QPU	= constant extraction by deep well	(m3.year-1)
$\tilde{N}^+$ =	PEXCMAX	= precipitation excess for very deep groundwatertables	(m)
r =	R(DI)	= radial distance from the well	(m)
r_1 =	RBOU	= radius of area where the ditches are dry	(m)
k =	KAQ	= hydraulic conductivity of the aquifer	(m.day-1)
H =	HAQ	= thickness of the aquifer	(m)
Λ =	RESISEPE	= resistance of the semi-pervious layer	(day)
γ_e =	RESITOP	= effective drainage resistance of toplayer	(day)
ξ =	XIL	= $\sqrt{K.H.(\Lambda+\gamma_e)}$	
K_0 =		modified zero order Bessel function of the second kind	
K_1 =		modified first order Bessel function of the second kind	
$Q(r)$ =	FLR(DI)	= quantity of water flowing into the aquif.	(m3.day-1)
$T_{aq}(r)$ =	TIAQ(DI)	= residence time in the aquifer	(year)
$T_{se}(r)$ =	TISEPE(DI)	= residence time in the semi-pervious layer	(year)
$T_{top}(r)$ =	TITOP(DI)	= residence time in the top layer	(year)
ε_{aq} =	PORAQ	= effective porespace in the aquifer	
ε_{se} =	PORSEPE	= effective porespace in the semi-pervious layer	
ε_{top} =	PORTOP	= effective porespace in the top layer	

5. DETERMINATION OF WATERTABLES (BLOC WIWA)

The drawdown of the average highest groundwatertable is calculated because this decline causes a decrease in denitrification and an increase in nitrogen discharge to the aquifer. This decline also influences the organic carbon present in the soil.

5.1. The winterwatertable before the pumping started

For many extraction-areas information about the average highest groundwatertable from the time before the pumping station has started is available. Sometimes however there is only information from after the pumping has started. When information about the original winterwatertable (the winterwatertable before the pumping has started) is available, the calculation of the winter watertable after the pumping has started is based on this information. When, on the other hand, only information about the mean winter watertable after the pumping has started is available the calculation of the original winterwatertable is based on this information. In the last case a correction factor has been introduced of 0.10 m to correct the influence of the pumping. This factor has been found as follows.
In areas with only freatic extractions the following has been found. The area where the drawdown of the phreatic level exceeds 0.05 m turned out to be the area where about 50% of the mean precipitation excess is used to feed the deep well extraction (Rijtema, 1982, report 4 ; figure 6). This drawdown will be present in a large part of the area; in the rest of the area the drawdown will be less. The extraction cone will be located relatively close to the extraction point. An estimation of the average drawdown has been been made by choosing a drawdown of 0.10 m. This value has been checked with the hydrological model from Ernst (1971) in the same three hydrological situations as described in the bloc HYDRO; 0.10 turned out to be a reliable value. A maximum deviation of 0.10 m (which means no drawdown) will be found when there is extraction from an aquifer situated underneath a thick semi-pervious layer with a high resistance.

5.2. Calculation of the winterwatertable after the pumping has started

To calculate the various winterwatertables, data from an investigation in the agricultural consequences from the groundwater extraction in Losser are used (RIJTEMA and BON, 1974). The winterwatertable after the pumping has started is calculated on basis of table 3, which has been derived from RIJTEMA and BON (1974; table 13).

Table 3. Relation between the average drawdown of the phreatic level and the drawdown of the average highest groundwatertable for various hydrological soil classes with their original groundwatertables.

hydr. soil class :	II	III	IV	V	VI	VII
orig.winterw.table:	.00	.20	.40	.30	.60	.90
average drawdown phreatic level	drawdown of av. highest groundwatertable					
.00	.00	.00	.00	.00	.00	.00
.20	.11	.15	.14	.16	.18	.20
.40	.24	.29	.28	.33	.37	.40
.60	.39	.45	.43	.51	.56	.60
.80	.54	.61	.58	.70	.75	.80
1.00	.69	.78	.75	.89	.94	1.00
1.20	.86	.97	.93	1.08	1.14	1.20
1.40	1.06	1.17	1.12	1.28	1.34	1.40
1.60	1.26	1.37	1.32	1.48	1.54	1.60

From these data an equation has been formulated to relate the winterwatertable after the pumping has started to the original winterwatertable. The drawdown of the average highest groundwatertable can be written as the difference between the average drawdown of the phreatic level and a correction factor. The relation between this correction factor and the hydrological soil class has been approximated with the following formula:

$$c = 0.3 * 0.1^{a} * (1 - 0.1^{b}) \qquad (16)$$

symbols: c = correction factor
a = original winterwatertable
b = average drawdown of the phreatic level

In this formula 0.3 is a maximum value for the correction factor independent from the original winterwatertable.
The expression (0.3 * 0.1**a) is an approximation for the asymptotes of the lines for various values of a. The drawdown of the average highest groundwatertable is given
by (b - c). The winterwatertable after the pumping has started is given by a + (b - c).

5.3. The relation between the average highest winterwatertable and the leaching of nitrate

Another correction factor is also calculated in this bloc. This factor represents the relation between the average highest groundwatertable and the quantities of nitrate nitrogen that leach out . STEENVOORDEN (~~ICW-nota nr.1435~~,1983) gives this relation as a table, from which the following formula has been derived:

$$c = \frac{1}{1.0 + e^{(-4.511*(d-0.685))}} \qquad (17)$$

symbols: c = correction factor
d = winterwatertable after the pumping has started
e = base of natural logarithm

6. VARIABLES AND CORRECTION FACTORS FOR THE FERTILIZATION-LEVEL (BLOC PROFERT)

In this chapter variables and correction factors are being dicussed that that are used to calculate the fertilization level. Five different types of manure is dealt with: cattle slurry, pig slurry, poultry slurry, wet and dry poultry manure.

6.1. The effective organic nitrogen in the extraction area

The total quantity of organic nitrogen in the extraction area is calculated as the total quantity of organic nitrogen produced by the animals in the extraction area plus the total quantity of organic nitrogen that is imported into the extraction area minus the total quantity of organic nitrogen that is exported from the extraction area.

The total organic nitrogen produced, imported and exported is calculated by multiplying the quantities of manure with the following factors:

1. The fraction of nitrogen present in the manure (given by LAMMERS et,al., 1983; table 1).
2. The application efficiency of the manure in relation to artificial fertilizer; LAMMERS et, al. (1983; table 18) give the following formulas for this efficiency-factor in a steady state situation:
   cattle slurry : 0.80*Nm + 0.69*Nnm (18)
   other manures : 0.80*Nm + 0.74*Nnm (19)
   Nm and Nnm are nitrogen fractions mineral (Nm) and non-mineral (Nnm) in relation to N-total; they are also given by LAMMERS et, al. (1983; table 2).
3. A factor indicating the relation between applications on grassland to applications on arable land. This factor has been found by calculating the average relation between the N-fractions of slurry- and dry manure-application on grassland and arable land.
4. A correction factor of 1000 for the inconsequent use of unities.

6.2. The nitrogen quantities in the manure

The quantities of nitrogen in the various kinds of manure that are used in the extraction area are calculated as follows. The quantities of nitrogen in cattle and pig slurry in the extraction area are calculated as the nitrogen production plus the import of nitrogen minus the export of nitrogen. The quantity of nitrogen in poultry slurry in the extraction area is calculated as the nitrogen production plus the import of nitrogen minus the export of nitrogen minus the quantities of slurry that are exported after being dried to wet or dry poultry manure. The quantities of nitrogen in wet and dry poultry manure in the extraction area are taken as the quantities of nitrogen import as wet and dry poultry manure respectively. So it is assumed that no poultry slurry that will be used in the extraction area is dried to wet or dry poultry manure.

6.3. The application time efficiencies

When manure is not applied in spring but in autumn or winter more of the manure will be lost for the crop. So the quantity of nitrogen that is applied in autumn or winter has to be multiplied by an efficiency factor, the application time efficiency, to find the quantity of nitrogen that is available for crop production in spring. This means that the efficiencies for spring application are 1 by definition. As the application time efficiencies for spring application are 1 by definition and for winter application are the average of the ones for autumn and for spring application only the efficiencies for autumn application have to be looked at now. Weighed averages of the efficiencies for grassland and arable land for the five kinds of manure are calculated on basis of the efficiencies for the various kinds of manure and the quantities of nitrogen in various kinds of manure that are used in the extraction area; these efficiencies are being discussed now.

For <u>arable land</u> the following formulas (LAMMERS et al. (1983)) have been used to calculate the nitrogen fractions available for crop.

autumn application:

- cattle slurry: (0.12*Nm + 0.64*Nnm) * Nfr (20)
- other manure : (0.12*Nm + 0.65*Nnm) * Nfr (21)

spring application:

- cattle slurry: (0.80*Nm + 0.69*Nnm) * Nfr (22)
- other manures: (0.80*Nm + 0.74*Nnm) * Nfr (23)

where:
- Nm = nitrogen fraction mineral (LAMMERS, 1983; table 2)
- Nnm = nitrogen fraction non/mineral " "
- Nfr = nitrogen fraction present in the manure " ;table 18)

Dividing of these fractions calculated for autumn application by the fractions for spring application provides the application time efficiencies for autumn application. The application time efficiencies for winter application are the averages of the values for autumn and spring application. The results are shown in table 4.

<u>Table 4.</u> Nitrogen fraction in various kinds of manure that is available for crop production in spring in case of autumn and spring application and the values of the application time efficiency in case of autumn, winter and spring application for arable land.

	N-fraction for crop		application time efficiency		
	autumn	spring	autumn	winter	spring
Cattle slurry	.00167	.00328	.51	.75	1
Pig slurry	.00212	.00424	.50	.75	1
Poultry slurry	.00251	.00704	.36	.68	1
Wet poultry manure	.00514	.00959	.54	.77	1
Dry poultry manure	.00864	.01611	.54	.77	1

For <u>grassland</u> the nitrogen fractions in the manure which will be available for crop production when the manure is applied in autumn and spring have been calculated on basis of formulas which are similar to the formulas for arable land. The formula for autumn application is:

N-fraction for crop = (0.16*Nm + 0.93*Nnm) * Nfr (24)

In this formula the coefficient with value 0.12 is substituted by 0.16. The value 0.12 is equal to 0.15, which is the fraction of Nm minus application losses that is available for crop production in spring, multiplied by the value 0.80, which takes into account the application losses. The value 0.15 is substituted by 0.23 and the value 0.80 by 0.68. So the product is 0.16. The value 0.23 was taken because 23% of the nitrogen applied at the first of November minus the application losses is harvested in the first harvest (LAMMERS et. al., 1984; table 8). It is assumed that it is 23% of Nm. The value 0.93 is from HENKENS. The formula for spring application is:

N-fraction for crop = (0.68*Nm + 0.96*Nnm)*Nfr

The coefficient with value 0.80, which takes into account the application losses of 20% of Nm for arable land, is substituted by 0.68, which takes into account the application losses of 32% of Nm for grassland. The application losses for grassland are greater because grassland is not ploughed after application of manure (EG-rapport 47, mentioned in LAMMERS, 1984). The value 0.96 is from HENKENS. Dividing of the fractions calculated for autumn application by the fractions for spring application provides the application time efficiencies for autumn application. The application time efficiencies for winter application are the averages of the values for autumn and spring application. The results are shown in table 5.

Table 5. Nitrogen fraction in various kinds of manure that is available for crop production in spring in case of autumn and spring application and the values of the application time efficiency in case of autumn, winter and spring application for grassland.

	N-fraction for crop		application time efficiency		
	autumn	spring	autumn	winter	spring
Cattle slurry	.00240	.00361	.66	.83	1
Pig slurry	.00300	.00451	.67	.83	1
Poultry slurry	.00352	.00688	.51	.76	1
Wet poultry manure	.00729	.01043	.70	.85	1
Dry poultry manure	.01225	.01751	.70	.85	1

The application time efficiencies are parameters used in the model to calculate the average application time efficiencies for grassland and arable land.

6.4. The leaching factors

To find the nitrogen leaching for a certain application time of the manure, the leaching in case of spring application has to be multiplied by a leaching factor. This means that the leaching factors for spring application are 1 by definition. The leaching factors for arable land and grassland have been calculated on basis of data about a normal fertilization level.

For arable land the nitrogen leaching is calculated as the sum of the nitrogen leaching in case of application of artificial fertilizer in spring and the extra leaching when manure is used in autumn or spring. The nitrogen leaching in case of application of artificial fertilizer is equal to 25% of the quantity of nitrogen that is available for crop production when the nitrogen requirement of the crop is applied (CURATORIUM LANDBOUWEMISSIE, 1980). The report of LAMMERS et. al. (1983; table 11) shows the formulas for the calculation of the fraction from the applied manure that is leached extra when manure is used in autumn or spring instead of artificial fertilizer in spring. The resulting formulas for the leaching nitrogen fraction of various kinds of manure are:

-autumn application:
  cattle slurry: (0.54*Nm + 0.19*Nnm + 0.25*(0.12*Nm + 0.64*Nnm))*Nfr
  other manures: (0.54*Nm + 0.19*Nnm + 0.25*(0.12*Nm + 0.65*Nnm))*Nfr
-spring application:
  cattle slurry: (0.13*Nnm + 0.25*(0.80*Nm + 0.69*Nnm))*Nfr
  other manures: (0.11*Nnm + 0.25*(0.80*Nm + 0.74*Nnm))*Nfr

The values for Nm, Nnm and Nfr have been taken from the report of LAMMERS et, al. (1983; tables 1 and 2). The resulting figures for the nitrogen leaching are shown in table 6. The leaching factor for autumn application has been calculated as the fraction of the nitrogen leachings in the cases of autumn and spring application. The leaching factor for winter application is the average of the factors for autumn and spring application.

Table 6. Nitrogen fraction in various kinds of manure that is leaching from the root zone in case of autumn and spring application and the values of the leaching factors in case of autumn, winter and spring application for arable land.

	leaching N-fraction		leaching factor		
	autumn	spring	autumn	winter	spring
Cattle slurry	.00202	.00111	1.82	1.41	1
Pig slurry	.00254	.00136	1.87	1.43	1
Poultry slurry	.00454	.00206	2.20	1.60	1
Wet poultry manure	.00563	.00315	1.79	1.39	1
Dry poultry manure	.00946	.00530	1.78	1.39	1

For grassland the nitrogen leaching is calculated as the sum of the nitrogen leaching in case of application of artificial fertilizer in spring and the extra leaching when manure is used in autumn or spring. There are three reasons why for grassland the equation which will be formulated for the use of cattle slurry is also used for the other four kinds of manure. The first is that enough information about the use of cattle slurry is available (LAMMERS et.al., 1984) while it is not available about the other four kinds of manure. The second is that on grassland cattle slurry is the kind of manure that is used mostly. The third reason is that because the formulas for the various kinds of manure for arable land hardly differ from each other this is also expected for the formulas for grassland.
The nitrogen leaching in case of application of artificial fertilizer in spring is equal to 15% of the quantity of nitrogen that is available for crop production when the nitrogen requirement of the crop is applied (STEENVOORDEN, 1983; figure 5). The quantities of nitrogen that are available for crop production are calculated with formulas similar to the formulas for arable land, but with different coefficients.
In case of spring application for the application losses for arable land 0.20*Nm has been taken, which means that 0.80*Nm was available for crop production. Because grassland is not ploughed after application of manure the application losses are greater. They are 0.32*Nm according to LAMMERS et. al. (1984), which means that 0.68*Nm is available for crop production. The fraction of Nnm that is available for crop production has been taken 0.96 on basis of data

from HENKENS.

In case of autumn application for arable land 0.15*0.8*Nm = 0.12*Nm has been taken. For grassland 0.23*0.68*Nm = 0.16*Nm has been taken. The value 0.68 has just been explained. The value 0.23 has been taken from LAMMERS et al. (1984). The fraction of Nnm that is available for crop production has been taken 0.93 on basis of data from HENKENS. The fractions from the applied manure that are leached extra when manure is used in autumn or spring instead of artificial fertilizer in spring are also calculated with formulas similar to the formulas for arable land. Only the coefficients are different. In case of spring application 0.09*Nnm has been taken. In case of autumn application 0.19*Nnm and 0.41*Nm have been taken.
In the case of arable land this was 0.68 * 0.80 = 0.54. For grassland it is (0.68 - (0.23-0.15)) * 0.68 = 0.41. The resulting formulas for the leaching nitrogen fractions of various kinds of manure for autumn and spring application are:

autumn: NLF= (0.41*Nm + 0.19*Nnm + 0.15*(0.16*Nm + 0.93*Nnm))*Nfr (30)
spring: NLF= (0.09*Nnm + 0.15*(0.68*Nm + 0.96*Nnm))*Nfr (31)

The resulting figures for the nitrogen leaching are shown in table 7 . The leaching factor for autumn application has been calculated as the fraction of the nitrogen leachings in the cases of autumn and spring application. The leaching factor for winter application is the average of the factors for autumn and spring application.

Table 7. Nitrogen fraction in various kinds of manure that is leaching from the root zone in case of autumn and spring application and the values of the leaching factors in case of autumn, winter and spring application for grassland.

	leaching N-fraction		leaching factor		
	autumn	spring	autumn	winter	spring
Cattle slurry	.00168	.00074	2.27	1.64	1
Pig slurry	.00210	.00092	2.28	1.64	1
Poultry slurry	.00362	.00127	2.85	1.93	1
Wet poultry manure	.00471	.00218	2.16	1.58	1
Dry poultry manure	.00791	.00367	2.16	1.58	1

Because it is unknown which manure is applied to which part of the extraction area it is necessary to attain one value for the leaching factor of the 5 kinds of manure. As the leaching factors for spring application are 1 by definition and for winter application are the average of the ones for autumn and for spring application only the leaching factors for autumn application have to be looked at now. Weighed averages of the leaching factors for grassland and arable land for the five kinds of manure are calculated on basis of the leaching factors for the various kinds of manure and the quantities of nitrogen in various kinds of manure that are used in the extraction area. These leaching factors are parameters used in the model.

6.5. The leaching-crop fractions

The leaching-crop fraction indicates the amount of nitrogen that leaches from the fraction of nitrogen available for crop (which can also be described as artificial fertilizer-equivalent of the total

amount of manure applied).
For grassland the leaching-crop fractions for the various kinds of manure are the fractions of the leaching nitrogen fraction for spring application (table 6) and the nitrogen fraction available for the crop for spring application (table 4). The leaching-crop fraction as well as the leaching factor have been derived for situations in which a normal nitrogen application to the crop is met only with manure. Table 8 shows the leaching nitrogen fractions for spring application, the nitrogen fractions for the crop for spring application and the leaching-crop fractions.

Table 8. The leaching nitrogen fractions for spring application, the nitrogen fractions for the crop for spring application and the leaching-crop fractions for grassland.

	leaching N-fraction spring	N-fraction for crop spring	leaching-crop fraction
Cattle slurry	.00074	.00361	.205
Pig slurry	.00092	.00451	.204
Poultry slurry	.00127	.00688	.185
Wet poultry manure	.00218	.01043	.209
Dry poultry manure	.00367	.01751	.210

For arable land the leaching-crop fractions for the various kinds of manure are the fractions of the leaching nitrogen fraction for spring application (table 5) and the nitrogen fraction available for the crop for spring application (table 4). The leaching-crop fraction as well as the leaching factor have been derived for situations in which a normal nitrogen application to the crop is met only with manure. Table 9 shows the leaching nitrogen fractions for spring application, the nitrogen fractions for the crop for spring application and the leaching-crop fractions.

Table 9. The leaching nitrogen fractions for spring application, the nitrogen fractions for the crop for spring application and the leaching-crop fractions for arable land.

	leaching N-fraction spring	N-fraction for crop spring	leaching-crop fraction
Cattle slurry	.00111	.00328	.338
Pig slurry	.00136	.00424	.321
Poultry slurry	.00206	.00704	.293
Wet poultry manure	.00315	.00959	.328
Dry poultry manure	.00530	.01611	.329

These leaching-crop fractions are used as parameters in the model to calculate the average leaching-crop fractions

6.6. The organic nitrogen excess

For the calculation of the organic nitrogen excess two cases have to be distinguished. In case the organic nitrogen requirement is greater than the quantity of organic nitrogen in the extraction area the organic nitrogen excess is equal to zero. In case the organic nitrogen requirement is less than the quantity of organic nitrogen in the extraction area the organic nitrogen excess is equal to the difference of these two.

7. THE FERTILIZATION LEVEL (BLOC FERT)

In this bloc the total nitrogen fertilization level per part (part of the area with a certain landuse) is calculated as the sum of the nitrogen delivery from the soil by mineralization of plant rests during growth, the quantity of effective organic nitrogen that is applied, the quantity of nitrogen applied as artificial fertilizer and the overdosing of organic nitrogen. To calculate this total nitrogen fertilization level per part, application times, the application-time efficiency and the overdosing of manure have to be calculated first.

7.1. The application time

The application times for the various parts will be determined on basis of the landuse and the winter watertable. For grassland with management agreement (landuse 1) only spring application is allowed. For intensively used grassland (landuses 2 and 3) the application time is dependent of the winter watertable. In case of a winter watertable higher than 0.2 m below ground level only autumn application is possible; in case of a winter watertable lower than 0.2 m below ground level application during the winter period is allowed. For a crop rotation of cereals, cereals, potatoes and beets (landuse 4) winter application is allowed. For foddermaize (landuses 5 and 6) application during winter is allowed. For horticulture and municipal areas (landuse 7 and 8) the application time is dependent of the winter watertable. In case of a winter watertable higher than 0.2 m below ground level only spring application is possible; in case of a winter watertable lower than 0.2 m below ground level application during the winter period is allowed. In case of forestland and non-fertilized natural land (landuses 9 and 10) no manure is applied, which means that it is unrealistic to speak about an application time. As it is necessary to have a value for the application time efficiency a choice has been made for spring application. In the case of land across bigger rivers (landuse 11), infiltrated river water is looked at. So not the fertilization of the land, but the nitrogen concentration of the riverwater is relevant.

7.2. The application time efficiency

The application time efficiencies for spring application are 1 by definition and for winter application they are the average of the ones for autumn and spring. The autumn application time efficiencies have already been calculated in the bloc PROFERT; in this bloc these values are related to parts of the area.

7.3. The overdosing of manure

The overdosing of manure (organic nitrogen excess) is expressed as pig slurry. Two cases are distinguished: with or without fertilization restrictions.
Without fertilization restrictions this excess is subsequently applied to the landuses 5,6,2,3 and 4 till the overdosing maximum is reached for all these landuses. In case a quantity of manure is still left

the fields with landuse 5 will be considered as dumpfields and the remainder is applied to these fields.
In the case of fertilization restrictions the nitrogen excess within the area with dump restrictions is dumped on the area with landuse 5 (continuously foddermaize with heavily dumping of slurry). In the area where no overdosing of manure is allowed the nitrogen excess will become zero.

7.4. The effective organic nitrogen and artificial nitrogen

For the calculation of the quantities of effective organic nitrogen and artificial nitrogen, which are applied to the landuses two cases are distinguished: in the first case there is an organic nitrogen shortage in the extraction area and in the second case there is an excess.
In case of an organic nitrogen shortage the fraction of the effective organic nitrogen requirement that is applied is the same for all landuses and it has to be equal to the relation between the organic nitrogen reauired and present in the extraction area. The quantity of artificial nitrogen which is applied is calculated as the balancing item of the nitrogen requirement.
In case of an organic nitrogen excess the quantity of effective organic nitrogen that is applied equals the organic nitrogen requirement and the quantity of artificial nitrogen that is applied is equal to the minimum dosis of nitrogen applied as artificial fertilizer.

7.5. The total nitrogen fertilization level per part

This is calculated as the sum of the total nitrogen mineralized plus the artificial and the effective organic nitrogen that are applied plus the nitrogen overdosing per part. The nitrogen mineralized is introduced as data. Origin of artificial and effective organic nitrogen have been explained already. The nitrogen overdosing per part is the product of the overdosing of manure expressed as pig slurry, a correction factor 1000 for the inconsequent use of unities, the nitrogen fraction in pig slurry which will be available for crop production when the slurry is applied in spring and the application time efficiency.

7.6. The atmosferic emission of nitrogen

Extended information concerning the atmospheric deposition of nitrogen on the soils in The Netherlands is given by VAN AALST and DIEDEREN (1982). The predominant sources are NOx from industrial emission and from traffic and NHx for about 90% originating from landspreading of animal slurries and animal housing. The mean deposition of anorganic nitrogen in The Netherlands as given by HOEKS (1983) is presented in table 10.

Table 10. Mean deposition of anorganic nitrogen in The Netherlands in 1980 in kg N per ha per year (HOEKS, 1980)

	NOx	NHx	total

dry deposition	11.2	18.5	29.7
wet deposition	5.9	9.5	15.4
total	17.1	28.0	45.1

The sources of the NHx deposition are given by BUIJSMAN et al. (1984):
- sources outside the agriculture: 10%
- volatilization in stables: 36%
- volatilization during fertilizer-application and during the period the fertilizer remains on the soil surface: 54%

The first two sources of the NHx deposition as well as the NOx deposition are considered to be constant and give a total deposition of 30 kg N per ha per year. In the model calculations half of it will be considered as winter-application and the other half as a spring application. The third source of the NHx deposition (emission of nitrogen by fertilizer-application) creates a variable deposition.

In outer-area and protection-area this variable emission for autumn, winter and spring is calculated as the sum of the emission of a part of the area. The emission of every part of the area with a different distance to the well and a different type of landuse is calculated by using the following equation:

$$E = \frac{0.13 * (OR+OV) * A}{0.74 * c * Atot} \qquad (32)$$

where:
E = variable emission caused by fertilizer-application
OR+OV = applied organic fertilizer
A = surface of part of the area
c = correction factor for the application time
Atot = total surface of the extraction area

(OR+OV) is the applied total organic fertilizer (effective organic plus overdosing).
The value of 0.74 is an average value for the application efficiency of manure in relation to artificial fertilizer and comes from Lammers et al. (1983; table 18).
The value of 0.13 indicates the nitrogen volatilization from different animal slurries and is found as follows. Assuming that 20% of the mineral nitrogen is lost by volatilization on arable land and 32% on grassland gives an average volatilization of 26%. Only mineral nitrogen (in this case NHx) will volatile and with a mineral fraction of 50% (Lammers et al., 1983, table 2) the nitrogen volatilization will be 0.5*0.26=0.13.

7.7. The atmospheric deposition in the outer-area

The atmosferic deposition in the outer-area equals the total emission per part of the area plus a constant emission of 15 kg N per ha per year in winter and spring.

7.8. The atmospheric deposition in the protection-area

In the protection area it is assumed that the deposition is proportional to the quantity of NHx present in the atmosphere. With this assumption the following equation holds:

$$dq/dt = E - a*q \qquad (1) \qquad (33)$$

where: q = quantity of NHx present in the atmosphere in kg.m-2 N
E = emission in kg.m-2.yr-1 N
a = deposition coefficient

Introduction of the mean horizontal wind velocity v = dx/dt gives:

$$dq/dx = -c*q + E/v \qquad (2) \qquad (34)$$

where: v = mean wind velocity in m.yr-1
x = downwind distance in m
c = a/v = mean deposition coefficient for bare soil

Integration of equation (2), with at distance x=0: q=q0 yields:

$$q = (q0 - E/a) * e^{-c*x} + E/a \qquad (3) \qquad (35)$$

where: q0 = the quantity of atmospheric N in kg.m-2 at the upwind boundary

Data given by Roelofs et al. (1983) show that the N deposition at 500 m distance downwind from a concentration of poultryholdings is about 50% of the deposition at very short distance. Close to the holdings the value of E in relation to a*q in equation (1) will be very small. Using equation (3) with E=0 and assuming a required travelling distance over bare soil in downwind direction of 500 m to reduce the atmospheric deposition from a point source to 50% of its initial value, results in a value of c equal to 0.00139 m-1. This value enters the model as data.
It appears that the deposition strongly depends on the type of vegetation covering the soil. Data given by Stuyfzand (1984) of the deposition of Cl- and SO4-- in relation to vegetation show that the relative deposition on bare soil, grass, natural vegetation, and trees equals 1.0, 1.6, 1.6, and 3.9. With these relative deposition factors the mean regional value of c as depending on vegetation can be calculated, using the areal fractions covered by the different vegetations in the catchment. The mean regional deposition coefficient can be calculated with the following equation:

$$cav = 0.00139 * 1/Atot * \sum_{s=1}^{s} Rs * As \qquad (36)$$

where: cav = mean regional deposition coefficient
Atot = surface of the extraction area
Rs = relative deposition for soiluse s
As = surface of the area with soiluse s

The mean regional E can be calculated on basis of the quantities of slurry applied for the various types of soiluse. For the outer-area it is assumed that dq/dt=0, so the deposition a*q equals E in that case. For the upwind boundary of the area the slurry application holds: q0=E0/a. The mean atmospheric deposition of NHx originating from landspreading of slurry in the protection-area equals:

$$D = \frac{1}{x}\left\{ \int_0^x (E_o - E_p)\, e^{-cav.x} \cdot dx + \int_0^x E_p \cdot dx \right\} \qquad (37)$$

or:

$$D = \frac{1}{cav}\left(E_o - E_p\right)\left(\frac{1 - e^{-cav.\sqrt{\pi}.R}}{\sqrt{\pi}.R}\right) + E_p \quad (40) \qquad (38)$$

where: D = the mean atmospheric deposition in the protection-area in kg.m-2.yr-1 N
Eo = the mean emission in the outer-area in kg.m-2.yr-1 N
Ep = the mean emission in the protected area in kg.m-2.yr-1 N
cav= the mean regional deposition coefficient in m-1
x = the downwind distance in m

In a circular shaped protection-area with a radius R the mean downwind distance x can be replaced aproximately by $\sqrt{\pi}$ *R. Equation (4) becomes in that case:

$$D = \frac{1}{cav}\left(E_o - E_p\right)\left(\frac{1 - e^{-cav.x}}{x}\right) + E_p \qquad (39)$$

With this equation the atmosferic deposition in the protection area is calculated in the model.

8. THE NO3-N CONCENTRATION IN THE AQUIFER (BLOC COAQ)

In this bloc the NO3-N concentration is calculated of the water in the aquifer at the point where it reaches the filter of the well.

8.1. The leaching factor

Leaching factors for grass and arable land with fertilizer application in autumn have been determined in the bloc PROFERT. The leaching factors for fertilizer application in spring are 1 by definition and for winter application they are the average of the ones for autumn and spring application. In this bloc these values are related to parts of the area and represent correction factors for the application time.

8.2. The nitrogen discharge to the denitrification zone

The denitrification zone starts at the groundwatertable. It is assumed that no denitrification takes place in the unsaturated zone because of aerobic conditions. The saturated zone is assumed to be anaerobic. The general formula used to calculate the nitrogen discharge to the denitrification zone is:

$$DIS = f1 \{ c1*MINE + c2*ART + f2*f3(OR+OV) + f4(c3*AU+c4*WI+c5*SP) \} \quad (40)$$

where: DIS = nitrogen discharge to denitrification zone
MINE = the mineralization of nitrogen
ART = the dosis of nitrogen applied as artificial fertilizer
OR = the dosis of nitrogen applied as organic fertilizer
OV = the over-dosis of organic fertilizer
AU = average atmosferic deposition in autumn
WI = average atmosferic deposition in winter
SP = average atmosferic deposition in spring
f1 = correction factor for the relation between the average highest groundwatertable and the leaching of nitrate
f2 = correction factor for the application time
f3 = correction factor for the nitrogen leaching from the fraction of nitrogen avaliable for crop in case of spring application
f4 = for very type of landuse a correction factor for the atmosferic deposition
c1,c2,c3,c4,c5: correction terms to indicate the amount of nitrogen leaching (discharge).

MINE varies with the type of landuse and enters the model as data.
ART, OR, OV, AU, WI, and SP are calculated and explained in the bloc FERT.
The calculation of f1 has been explained in the bloc WIWA.
f2 has been calculated and explained in the beginning of this bloc.
f3 has been calculated and explained in the bloc PROFERT.
f4 has been calculated and explained in the bloc FERT.
For <u>arable land</u> the nitrogen leaching of the nitrogen from mineralization and the artificial nitrogen application is 25% when the nitrogen requirement of the crop is applied (CURATORIUM

LANDBOUWEMISSIE, 1980); this means that c1 and c2 are 0.25.
For grassland nitrogen leaching of the nitrogen from mineralization is nihil, therefore c1=0; the nitrogen leaching from artificial nitrogen application is 15% (Steenvoorden, 1983; figure 5/Rijtema, mond.meded.) therefore c2=0.15
The atmospheric deposition has been calculated for the outer-area and the protection area as has been explained in the bloc FERT. The correction term c5 is equivalent to c2, c3 is taken from Lammers et al. (1983; table 4) and c4 is the average of c3 and c5.

In case of land across a big river the nitrogen concentration of this river together with the precipitation excess determine the nitrogen discharge to the denitrification zone.

8.3. The denitrification with carbon leaching from the unsaturated zone

The most important physical factors influencing the denitrification process are availability of organic carbon, temperature, pH and nitrate concentration (STEENVOORDEN, 1977).
The denitrification reaction can be described as a first order biodegradation of carbon:

$$\frac{dC}{dt} = -k * C \qquad (41)$$

where: C = carbon concentration
t = time
k = reaction rate coefficient

In the bloc COAQ the temperature is assumed to be constant throughout the top layer and the semi-pervious layer. It is taken into account in the reaction rate coefficients (k) for the denitrification reactions.
The rate of denitrification is proportional to a pH-factor (fpH) with which the reaction rate is multiplied. This pH-factor is calculated in this bloc with a formula that is derived in the report of STEENVOORDEN (1983).

$$fpH = \frac{1}{1 + e^{-1.916(pH-5.457)}} \qquad (42)$$

As the formula has not been fit for pH-values greater than 8 the program is stopped in case a pH higher than 8 is used as input value.
The rate of denitrification is also proportional to the following nitrate factor:

$$\frac{(NO3\text{-}N)}{c + (NO3\text{-}N)} \qquad (43)$$

For some investigations a value for c which is less than 2 g/m3 N is found (KNOWLES, 1981). For a NO3-N-concentration which is greater than 5 g NO3-N/m3 the nitrate factor is greater than 0.7. This is one reason why the model has been kept simple by not taking nitrate into account as a limiting factor. Another reason is that in case of a low value for the nitrate leaching to the saturated zone normally the leaching is greater than the discharge to the denitrification zone

which means that the discharge to the aquifer is zero, independent from the exact value of the leaching as can be seen later in this paragraph.
The resulting formula is:

$$\frac{dC}{dt} = - k * fpH * C \qquad (11) \qquad (44)$$

Integrating of this formula with the boundary condition that at t = 0: the carbon leached out of the aquifer equals the amount of carbon that leaches out of the unsaturated zone. The resulting formula is:

$$C = C0 * e^{- k * fpH * t} \qquad (45)$$

where: C = carbon leaching from the aquifer
C0 = carbon leaching from unsaturated zone
k = reaction rate coefficient
t = residence time

In the model this formula is applied to the three layers.
On basis of data from Lammers et al. (1983; annex 1) a value for k of 0.05 has been taken. The values for fpH and t vary for the various layers.
C0 (the carbon leaching from the unsaturated zone) is determined with the following formula:

$$C0 = 0.2 * (OR+OV) * e^{-5 * WI} \qquad (46)$$

where: C0 = carbon leaching from the unsaturated zone
OR = dosis of nitrogen applied as organic fertilizer
OV = over-dosis of organic fertilizer
WI = winterwatertable after the pumping has started

This formula has been determined on basis of various data present on the institute. The denitrification (as nitrogen concentration) caused by the carbon that has leached out is the product of the quantity of dissolved organic carbon that is used for the denitrification reaction and the nitrogen-carbon ratio (N/C). The quantity of dissolved organic carbon that is used for the denitrification reaction is calculated as the difference between the carbon leaching from the unsaturated to the saturated zone and the carbon leaching from the aquifer to the filters of the well The resulting formula for the calculation of the denitrification with the carbon from the unsaturated zone is:

$$DEN = N/C * (C0 - C) \qquad (47)$$

where: DEN = denitrification with carbon leaching from the unsaturated zone
N/C = nitrogen/carbon rate
C0 = carbon leaching from the unsaturated zone
C = carbon leaching from the aquifer

The nitrogen-carbon ratio is the quantity of nitrate-nitrogen which can be denitrified per quantity of organic carbon. The values for N/C for denitrification to N2O and N2 respectively are 1.17 and .99 (FIRESTONE, 1982). A value for N/C of 1.0 will be acceptable in most cases.

8.4. The denitrification with solid organic carbon

Before the denitrification which is possible with the concentration of solid organic carbon in the three layers can be calculated the concentration of solid organic carbon in the layers has to be calculated. This is calculated as the product of the density of the layer, the organic fraction of the layer and the carbon fraction of the organic material. For the carbon fraction of the organic material a value of 0.58 has been taken (Rijtema, mond. meded.).

The formula for the calculation of the denitrification with solid organic material is derived as follows. Formula (1) can be written as:

$$dC = - k * fpH * C * dt \qquad (48)$$

Because the process takes place in the saturated zone the porosity is used instead of the porespace filled with water. When C is assumed to be constant in the time all factors before dt are constant and the denitrification in g/m3 water for a period of time can be calculated. Substitution of the residence time for dt gives the following formula.

$$DEN = k * N/C * (fpH * 1/\varepsilon * C * T) \qquad (49)$$

where: DEN = denitrification with solid organic carbon
k = reaction rate coefficient
N/C = nitrogen-carbon ratio
fpH = pH-factor of the layer
ε = porosity of the layer
C = carbon concentration of the layer
T = residence time in the layer

A value for k of 0.005 is derived from k-values given in Rytema (1980; page 140). This value of 0.005 has been chequed with a calculation on basis of data from a deep lysimeter experiment of STEENVOORDEN (1983).

8.5. The maximum denitrification in the subsoil

The maximum denitrification with carbon available in the subsoil is calculated as the sum of the denitrification which is possible with the dissolved organic carbon that is leaching from the unsaturated to the saturated zone and the denitrification which is possible with the concentration of solid organic carbon in the layers.

8.6. The nitrogen discharge from the aquifer

The nitrogen discharge to the denitrification zone minus the maximum denitrification gives the nitrogen discharge form the aquifer. If this discharge turns out to be negative it is set to zero.

The rest of this bloc is used to totalize nitrogen loads and to relate the values for nitrogen loads to areas.

9. THE NO3-N CONCENTRATION AT THE EXTRACTION POINT (BLOC COPU)

In this bloc the NO3-N concentration is calculated of the water that is pumped up at the extraction point after certain periods of time. In the beginning of this bloc a few variables are determined to indicate the periods used in the calculations.

For every 10 years in this part of the bloc the NO3-N concentration is calculated in streamtubes. This concentration depends on the origin of the water that reaches the extraction point and the residence time.
The origin of the water may be one of the following:
- water from the time before the pumping started
- water from the time after the pumping started; no fertilizing restrictions
- water from the time after the fertilizing-restrictions started

This leads to three different NO3-N concentrations in the streamtube:
C0 = NO3-N concentration before the pumping started (enters the model as an input-variable)
C1 = NO3-N concentration after the pumping started; no fertilizing-restrictions
C2 = NO3-N concentration after the fertilizing-restrictions started (C1 and C2 are calculated in the bloc COAQ)
The different residence times of water in the bounding streamlines of the streamtube lead to the six situations given in figure 1

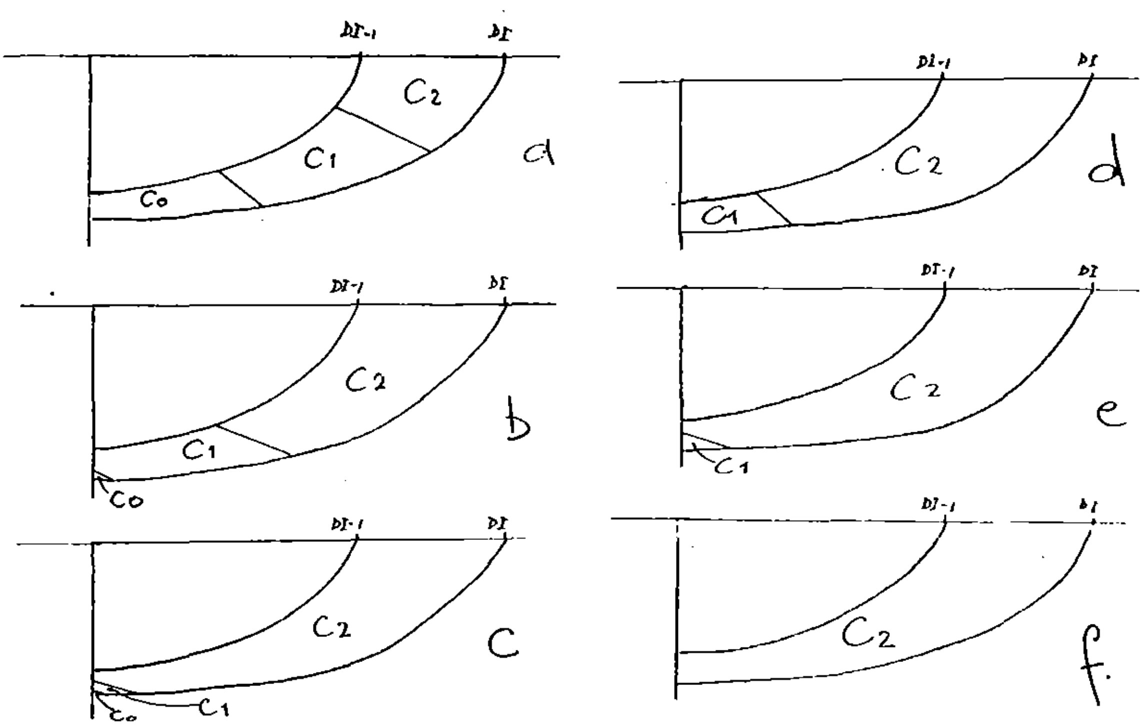


fig 3. Schematization of the - - - - -

figure 1 A transsection of a streamtube in an extraction area with the three different NO3-N concentrations in six situations.

Depending on the residence time in the bounding streamlines, in three situations (figure 1b, 1c and 1e) the NO3-N concentration of the water at the extraction point is calculated as a weighed average of the NO3-N concentrations in the water reaching the extraction point.

The rest of this bloc is used to relate the calculated values of the NO3-N concentration to areas and periods.

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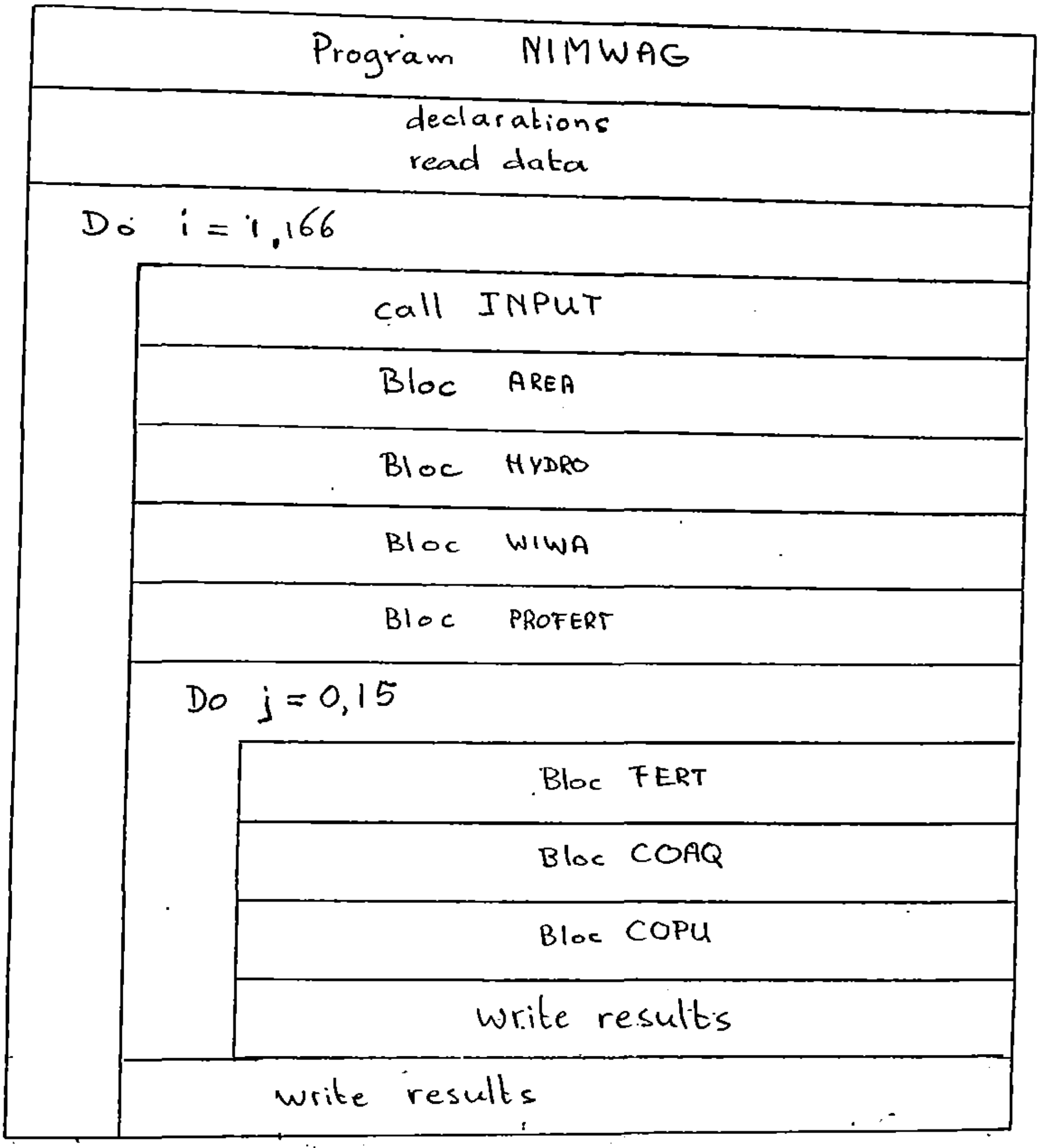
ANNEX 1.



structure diagram of the program NIMWAG

ANNEX 2: LETTERS AND COMBINATIONS OF LETTERS USED TO FORM VARIABLES

List of letters and combinations of letters which are used to form the names of the variables.

AC	actual
AGE	number of years since the pumping station started pumping
AN	anaerobic
AP	application
AQ	aquifer
AR	arable land
ART	artificial fertilizer
AU	autumn
AV	average
B	Bessel
BOU	boundary
C	counter
CA	carbon
CAT	cattle
CO	nitrogen concentration
COEF	coefficient
CR	crop
DEN	denitrification
DENS	density
DEP	atmospheric deposition
DEPTH	depth of streamlines
DI	difference, index for radius
DIS	nitrogen discharge
DIST	distance
DR	dry manure
DU	dump
EF	effective, efficiency
EX	export
EXC	excess
EXP	exponent
EXT	extraction area
F	first
FA	factor
FEED	groundwater feed
FER	fertilizer, fertilization
FL	flow
FR	fraction
GR	grassland
H	highth of a geological layer
HO	horticulture
IM	import
IN	in
LE	leaching
LI	limit(ation)
LO	nitrogen load
MA	maize
MAN	manure
MAX	maximum
MIN	minimum
MINE	mineralization

N	nitrogen
NU	number
OP	optimum
OPT	option
OR	organic
ORI	original
OUT	out
OV	overdosing
P	precipitation
PA	part
PH	pH
PI	pi
PIG	pig
POR	porosity
POT	potential
POU	poultry
PRO	production
PU	pumping
Q	water extraction
R	radius
RA	ratio
RE	restriction, restricted
REL	relative
REQ	requirement
RESI	resistance
RIV	river
SA	saturated
SEPE	semi-pervious layer
SO	soil, upper part of the top layer, solid
SL	slurry
SP	land spreading, spring
SU	sub
T	total
TI	time
TOP	top layer
TRA	transport
U	unit
UN	unrestricted (by agricultural measures)
UNIT	unit
UNLI	unlimited
UNSA	unsaturated
USE	landuse
V	index for the loop with restrictions
W	wet manure
WA	water
WE	well
WI	winter
XIL	xil
Y	year
ZO	zone

ANNEX 3: VARIABLES IN THE DATA-FILE NIMWAG.IN

variable	description	default	format
EXTMIN	:first extraction area to start calculations	1	I10
EXTMAX	:number of extraction areas to calculate	166	I10
REMAX	:maximum number of restrictions	15	I10
YEARRE	:year in which restrictions start	1988	I10
DIR	:difference in radius	200.	I10
CORIV	:N-concentration of river crossing the area	1.	F10.0
DENSAQ	:density of the aquifer	1600.	F10.0
DENSSEPE	:density of the semi-pervious layer	1600.	F10.0
DENSTOP	:density of the top-layer	1600.	F10.0
PEXCMAX	:maximum precipitation excess (Ernst '71, p.172)	.3000	F10.4
COAQNOPU	:N-conc. in the aquifer before pumping started	.5000	F10.4
PORAQ	:porosity of the aquifer	.3500	F10.4
PORSEPE	:porosity of the semi-pervious layer	.3500	F10.4
PORTOP	:porosity of the top layer	.3500	F10.4
ORFRAQ	:organic fraction in the top-layer	.0000	F10.4
ORFRSEPE	:organic fraction in the top-layer	.0000	F10.4
ORFRTOP	:organic fraction in the top-layer	.0015	F10.4

ANNEX 4: VARIABLES ORIGINATING FROM LD, LEI AND STIBOKA

Annex 4a. Data originating from the LD

variable	description	unity	format
NAME	:name community-pumping station	(-)	A40
HTOP	:higth of top-layer	(m)	F10.0
HSEPE	:higth of semi-pervious layer	(m)	F10.0
HAQ	:higth of aquifer	(m)	F10.0
RESITOP	:effective rainage resistance	(d)	F10.0
KSEPE	:permeability of semi-pervious layer	(m/d)	F10.4
KAQ	:permeability of the aquifer	(m/d)	F10.0
QPU	:water extraction	(m3/yr)	F10.0

Annex 4b. Data originating from the LEI

STULM	:community number	(-)	I10
LEI(2)	:area in rotation	(ha)	F10.0
LEI(3)	:area of maize	(ha)	F10.0
LEI(4)	:area of grass	(ha)	F10.0
LEI(5)	:rest of the area	(ha)	F10.0
LEI(6)	:total agricultural area	(ha)	F10.0
SLPROCAT	:total cattle-slurry production	(t)	F10.0
SLPROPIG	:total pig-slurry production	(t)	F10.0
SLPROPOU	:total poultry-slurry production	(t)	F10.0
DRPROPOU	:total poultry dry manure production	(t)	F10.0
NGR	:amount of nitrogen reguired for grassland	(kg)	F10.0
NAR	:amount of nitrogen reguired for arable land	(kg)	F10.0
MANEXC(1)	:manure excess option 1	(t)	F10.0
	(application in nov/mar. 100%N-applied,as: 100% org 0%art.)		
MANEXC(2)	:manure excess option 2	(t)	F10.0
	(application in nov/mar. 100%N applied,as: 75% org 25%art.)		
MANEXC(3)	:manure excess option 3	(t)	F10.0
	(application in nov/mar. 75%N-applied,as: 75% org, 25% art.)		
MANEXC(4)	:manure excess option 4	(t)	F10.0
	(application in nov/mar. 50%N-applied,as: 100% org, 0% art.)		
MANEXC(5)	:manure excess option 5	(t)	F10.0
	(application in nov/mar. 50%N applied,as: 75% org, 25% art.)		
MANEXC(6)	:manure excess option 6	(t)	F10.0
	(application in nov/mar. 50%N applied,as: 50% org, 50% art.)		
MANEXC(7)	:manure excess application in march	(see MANEXC(1))	
MANEXC(8)	:manure excess application in march	(see MANEXC(2))	
MANEXC(9)	:manure excess application in march	(see MANEXC(3))	
MANEXC(10)	manure excess application in march	(see MANEXC(4))	
MANEXC(11)	manure excess application in march	(see MANEXC(5))	
MANEXC(12)	manure excess application in march	(see MANEXC(6))	

Annex 4c. Data originating from STIBOKA

STARTPUOR	Iyear in which the pumping started	I10
SURVEY	:year in which the groundwater-tables were determined	I10
FRAGR	:fraction-area with agricultural landuse	F10.2
FRWIWA(2)	:fraction-area with winter watertabel I+II	F10.2
FRWIWA(3)	:fraction-area with winter watertabel III	F10.2
FRWIWA(4)	:fraction-area with winter watertabel IV	F10.2
FRWIWA(5)	:fraction-area with winter watertabel V	F10.2

FRWIWA(6):fraction-area with winter watertabel VI F10.2
FRWIWA(7):fraction-area with winter watertabel VII F10.2