Impact of climate change and land subsidence on the water systems in the Netherlands

Terrestrial areas

Authors:
M. Haasnoot
J.A.P.H. Vermulst
H. Middelkoop

Ministerie van Verkeer en Waterstaat

Directoraat-Generaal Rijkswaterstaat

RIZA Rijksinstituut voor Integraal Zoetwaterbeheer en Afvalwaterbehandeling

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Summary

This report contains the results of a study on the impacts of climate change and autonomous developments on the regional water systems in the Netherlands. The effects have been calculated with a comprehensive set of coupled hydrological (NAGROM, MOZART, MONA), eco-hydrological (DEMNAT) and agro-hydrological (AGRICOM) models. In addition, a more qualitative description is given, which is based on interviews and literature research.

To asses the impacts of climate change two reference scenarios and two climate scenarios have been considered. The reference scenarios include a hydrological situation for the present situation (REF95) and a situation for the year 2050 (REF2050), which includes the autonomous developments. The autonomous developments considered in this survey are land subsidence, changes in land use and sea level rise. The changes in land use were based on different socio-economic scenarios, defined by CPB (Kors *et al.*, 1996). The climate scenarios were based on the central estimate for the year 2050 (CEN2050) and the upper estimate for the year 2100 (UPP2100) from the greenhouse emission scenario from IPCC (IPCC, 1995). In table 1, the characteristics of the climate scenarios are summarised.

Table 1. Characteristics of the two climate scenarios.

Scenario	Temp. Rise	Sea level rise	Δ winter precipitation	Δ summer precipitation	Δ reference evaporation	Δ transpiration
CEN2050	+ 1 °C	+ 25 cm	6%	1%	4%	- 4 - - 12 %
UPP2100	+ 4 °C	+ 110 cm	25%	4%	15%	- 8 - - 25 %

The model results are presented in terms of changes on the computed hydrological parameters between the present situation and the calculated scenarios. The autonomous developments have a small effect on the average mean spring groundwater level; 45 % of the total area does not change. Other areas show an increase or decrease of approximately 10 - 25 cm. Impacts of changes in land use depend strongly on the kind of change and the changes in evapotranspiration this produces. Climate change results in a groundwater level increase of 4 - 5 cm for CEN2050 and 10 - 15 cm for UPP2100. In some areas (Friesland and Holland), the mean lowest groundwater level decreases, especially within UPP2100, due to the high drainage densities.

Land subsidence increases the elevation gradient between the Holocene and Pleistocene area, resulting in intensified infiltration fluxes in infiltration areas and less upward seepage in seepage areas in the Pleistocene part of the Netherlands. In the Holocene part the opposite occurs. In areas with reclaimed lakes, the elevation gradient between the sandy former lake area and the surrounding peat area decreases, resulting in a decrease in fluxes. The increased precipitation in the climate scenarios results in intensified infiltration in infiltration areas and more upward seepage in seepage areas.

The annual discharges increase with an average of 12 % for the CEN2050 and 25 % for the UPP2100. The autonomous developments result in minor changes of the annual discharges. Changes in salt loads are mainly caused by land

subsidence. The relative amount externally supplied water from the river Rhine does not change considerably in this study.

In general, the modelled hydrological changes have a positive impact on the wet terrestrial nature of the Netherlands. The results of DEMNAT indicate that the autonomous developments have limited ecological effects compared to the climate change scenarios. A stronger climate change results in a larger increase of the total conservation values. Especially the oligotrofe ecotopes contribute to this increase. The more (weakly) acid ecotopes show only a light increase or even a decrease in conservation value, because they grow mainly in areas with a decrease of the mean spring groundwater level. Wetter conditions, as predicted by the models will decrease the desiccation problems in most areas. However, these problems will not be solved as the 'background desiccation' for the Netherlands is approximately 30 cm and the average increase of the modelled groundwater levels in nature conservation areas, is less than 5 cm. Furthermore the CO_2 and temperature rise may influence the composition of the vegetation.

In the REF2050 scenario both the drought and water logging damage for the whole Netherlands decrease with respectively 22 and 118 millions DFL. The change of agriculture to nature or urban area reduces the total area of agriculture and consequently the total damages for the Netherlands in this scenario. However, the impact of land subsidence might be underestimated, because of the assumption that water management will follow the land subsidence by adapting the drainage depth. Climate change results in a small reduction of the drought damage and a considerable increase of the water logging damage. A comparison with the REF2050 scenario indicates an increase of the water logging damage of 52 millions DFL for the CEN2050 scenario and 162 millions DFL for the upper estimate of 2100. Also the sprinkling demands will increase as a result of a higher chloride concentration in the surface water. Other effects, put forward by the experts from the agriculture sector, are for example the loss of early spring harvest of grass, introduction of alternative crops or increase of agricultural pests and diseases.

Impacts on water management depend strongly on the present margins in water management. The foreseen problems include mainly the capacity to discharge water to prevent flooding in winter and to get fresh water for sprinkling and flushing in summer.

Possibilities of mitigating measures can be found in accepting, adapting or mitigating the hydrological changes caused by the autonomous developments and climate change. The first two kinds of measurements are more sustainable. Examples of these precautions are: agricultural nature conservation, water storage and inundation areas, cultivation of other crops or changing the water system function. Technical measures which mitigate the impacts of wetter conditions are for example: increasing the drainage intensity and pumping capacity.

It is recommended to do more research on the impact of increased atmospheric CO_2 concentration on the total transpiration of plants. In addition the impacts of climate change on changes in discharges of rural areas over the year, especially from the river Rhine, can be quantified better by coupling the used hydrological models to a surface water distribution model.

Contents

1 Introduction

The increase of greenhouse gases such as carbon dioxide and the ozone depletion will increase the heat trapping within the atmosphere and eventually warm the climate. Since 1995, the impact of climate change on the river Rhine and the implication for the Netherlands' water management system has been studied by RIZA, within the scope of the Dutch National Research Programme on Global Air Pollution and Climate Change. This project consists of two parts, namely:

- the river basin project, which assesses the impact of climate change on the river regime of the river Rhine and
- the impact on inland water systems and water management in the Rhine basin part of the Netherlands, which assesses the impact of climate change on the regional water balance and soil hydrology.

The latter part can be subdivided into the following sub-projects:

1. impact on the Rhine and the Rhine basin,
2. impact on the lake IJsselmeer,
3. impact on the terrestrial areas.

This report describes the results of the last sub-project, the impact on terrestrial areas. The aim of the project was to determine and compute the effects of climate change and land subsidence on the regional hydrology and functions of this regional hydrology (nature and agriculture) in the Netherlands. This has been determined using a coupled set of hydrological, eco-hydrological and agro-hydrological simulation models. The models have been applied to different scenarios. Two climate scenarios have been compared to two reference scenarios; the present situation (REF1995) and a reference situation for 2050 (REF2050). Within REF2050, different autonomous developments have been implemented, such as land subsidence, changes in land use and autonomous sea level rise. The scenarios are different in intensity of climate change and sea level rise (table 5). The scenarios should be considered as 'what-if'-scenarios. Consequently, the computed effects are estimates of what happens if the conditions defined within the scenario would occur, rather than a prediction of the hydrological situation in 2050 or 2100.

First the impacts of temperature rise, increasing precipitation and evaporation and sea level rise on the regional hydrology have been determined. In addition, in order to obtain better qualitative understanding of processes, such as transpiration and land subsidence, a literature review has been carried out. The calculated hydrological changes like groundwater levels, upward and downward seepage fluxes and surface water levels have been used as input for the eco-hydrological and agro-hydrological models to estimate the impact on nature and costs and benefits for agriculture. The results have been discussed with different persons involved to get an idea of the severity of the predicted impacts and to determine possibilities of mitigating measures.

Outline

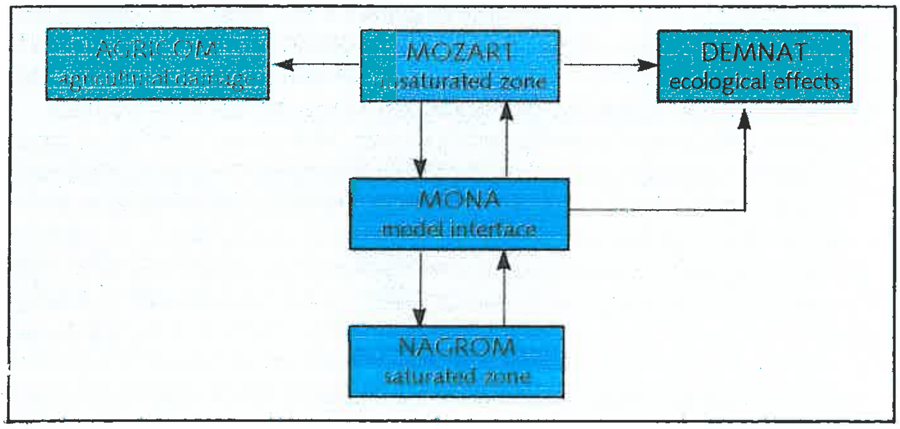
A short description of the models is given in chapter 2. The reference and climate scenarios are presented in chapter 3. The results of the hydrological model computations are given in chapter 4. The impacts of the computed hydrological changes caused by climate change on different functions, computed with an agro- and ecohydrological model, are described in chapter 5. Chapter 6 gives an evaluation of the impacts of climate change. Finally, the conclusions and recommendations are given in respectively chapter 7 and 8.

2 Modelling approach

2.1 Introduction

The impacts of climate change, land subsidence and changes in land use have been determined with a comprehensive set of hydrological models. Figure 1 presents the interactions between the different models. The hydrological models are given in blue, these are: a model for the unsaturated zone (MOZART), a model for the saturated zone (NAGROM) and a linking model between these models (MONA). The models used to determine the impacts for functions are given in green. These models are the eco-hydrological model DEMNAT and the cost and benefit model AGRICOM, used to determine respectively the impacts of the hydrological changes on nature and agriculture. MODEM translates the hydrological changes to input for the eco-hydrological model. This chapter gives a description of the models used.

Figure 1. Interaction between the hydrological models.



2.2 Hydrological models

2.2.1 Model concept

The hydrological effects of the reference scenario and the climate scenarios have been computed on nation- wide scale using the NAtional GROundwater Model (NAGROM, De Lange, 1996) and a MOdel for the unsaturated Zone for national Analyses and Regional applicaTions (MOZART, Ontwikkelteam NAGROM-MOZART-DEMNAT-AGRICOM, 1997). NAGROM is a steady state model based on the Analytic Element Method (AEM; Strack,1989). It models the entire groundwater system in several aquifers and aquitards, down to an impermeable base (Tertiary deposits).

Figure 2 shows the used schematisation of the hydrological top system (figure 2), which consists of a top system layer with one or two drainage systems underlain by the first semi-permeable layer. In polder areas, where the surface level is maintained artificially, only one drainage system has been distinguished.

In the other parts of the Netherlands, drainage takes place by gravity. Here, the hydrological system consists of two drainage systems. The hydrological top system has been modelled within both models. The behaviour of this top system is modelled in a lumped manner, using a linear relation between groundwater heads in the first aquifer and the fluxes towards the different drainage systems (De Lange, 1996).

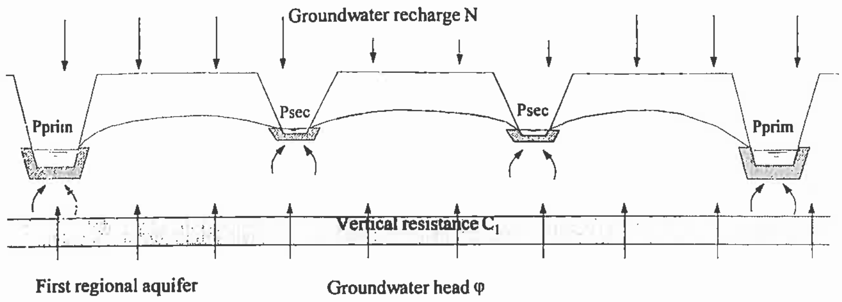


Figure 2. Hydrological top system modelled within NAGROM and MOZART. Pprim is the primary water level which is for example the surface water level in rivers and canals. Psec is the secondary drainage level, which is for example the surface water level in ditches.

The upper boundary of NAGROM comprises the water levels in the drainage systems, precipitation surplus computed by MOZART and the feeding resistance. The feeding resistance is the resistance experienced by a groundwater particle when flowing from the first aquifer to one of the drainage systems.

Horizontally, the schematisation of the top system of NAGROM consists of quadrilateral elements (also called area-sinks) of approximately 1 to 5 km². Within an element, the hydrology is assumed to be uniform. This means that the feeding resistances, drainage levels and groundwater recharge do not change within an element. Therefore, the elements should match different hydrological areas and features as well as possible. The groundwater flow is computed with analytical functions. This results in a continuous distribution of computed heads in the first aquifer over the model area.

MOZART simulates the unsaturated zone as vertical groundwater flows through a vertical soil column, which consists of an effective root soil and a subsoil. These plots coincide with gridcells of 500 x 500 m². Groundwater flows between adjacent plots is assumed to take place through the first aquifer by means of an upward or downward seepage flux. The upper boundary condition of MOZART is given by precipitation and reference evaporation for subsequent ten-day intervals. The lower boundary of the model is the seepage flux between the first aquifer and the hydrological top system through the first semi-permeable layer. Seepage fluxes are derived from the results of NAGROM using the linking tool MONA.

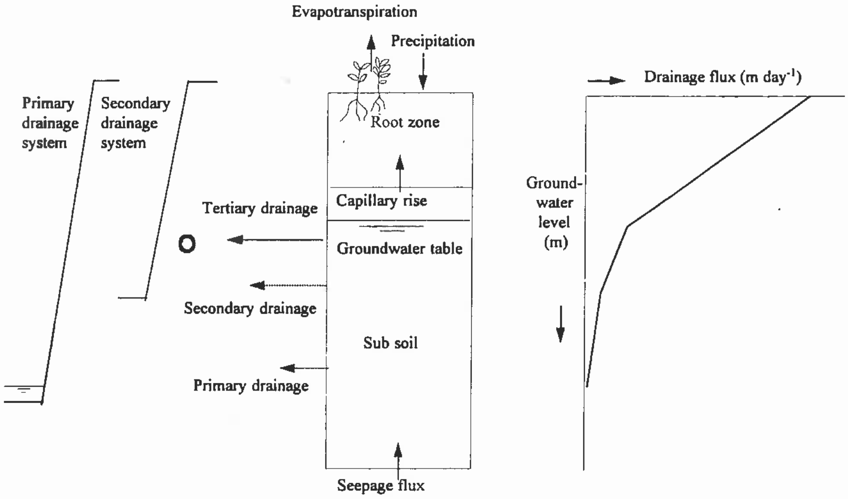


Figure 3. Plot schematization in MOZART and drainage function used within MOZART.

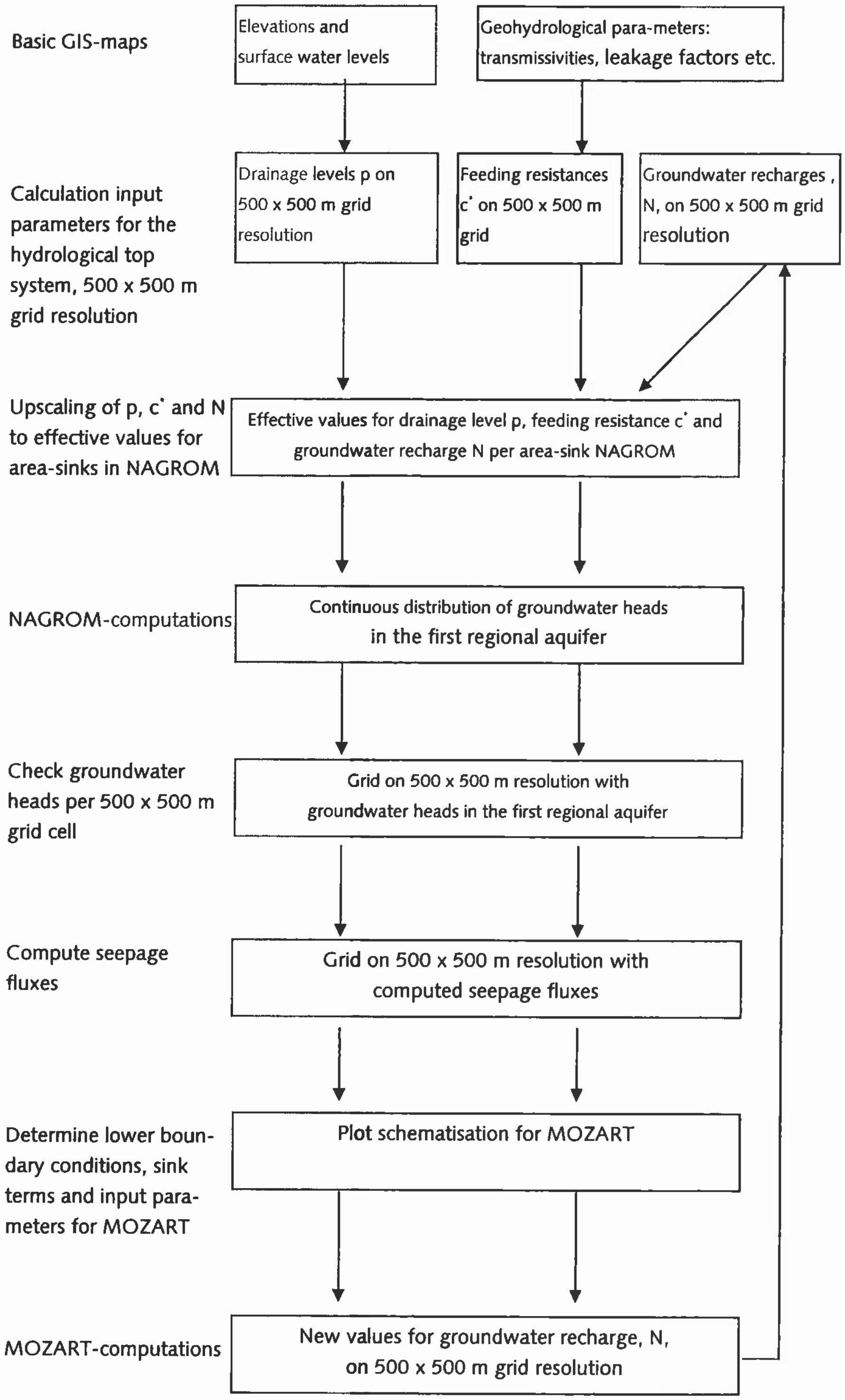
MOZART considers three different drainage systems (figure 3), from which the first corresponds with that of NAGROM. This first drainage system represents the drainage by canals and brooks. The secondary and tertiary drainage system represents respectively drainage to ditches and artificial drains. These drainage systems coincide with the second drainage system of NAGROM after a lumping procedure. For the computation of drainage, so-called drainage functions have been used. These are broken linear relations between groundwater levels and the drainage fluxes. The slopes represent the drainage resistance, which is defined as the resistance between the groundwater table and the drainage system, while the intersections reflect the drainage levels. The model results include amongst others groundwater levels, surface water levels and seepage fluxes per plot, and the demand for external water supply per local surface water unit.

The linking tool MONA (figure 4; Vermulst *et al.*, in prep.; De Haan, 1998) is used to connect the models of the unsaturated and the saturated zone. It consists of a set of Arc-Info Macro Language and Fortran programs and generates the upper boundary of NAGROM and the lower boundary of MOZART. The hydrological parameters are derived from geographical information. An up- and down scaling procedure enables proper transport of data between the two models.

Because both models depend on each other's outcomes, the computation is an iterative process. First, the hydrological top system is parameterised with drainage levels and feeding resistances with a resolution of 500 x 500 m, based on geographical and geohydrological information of for example elevation, surface water levels, leakage factors and transmissivity. For a first computation with NAGROM, these values are translated into effective values for the area sinks and a continuous distribution of groundwater heads is computed based on groundwater recharge fluxes estimated from earlier model results. Subsequently, seepage fluxes can be computed from a grid with the calculated groundwater heads, the lower boundary for MOZART. Together with information on land use, reference precipitation and reference evaporation per ten-day interval, groundwater heads are the input of MOZART. Within MOZART, reference evaporation figures are transformed into evapotranspiration amounts, using crop factors, which are variable over a year and defined for five crop types (De Bruin, 1981). The geographical variation of the crop factor is derived from a land use database.

The first computation with MOZART gives new estimations of the precipitation surplus, which is a boundary condition for a second computation with NAGROM. After a second computation with NAGROM, which gives new groundwater heads, a second computation with MOZART is carried out. When the groundwater recharges, computed by MOZART, equal the values used in NAGROM, the models are fully coupled. In that case, water balances are equal. In most cases, this occurs after two iterations. The outcome of the second run is used in determining the effects of the scenario. The results of MOZART were considered as less accurate in the higher sandy areas (dune and ice-pushed ridges). Therefore, the results of NAGROM have been used in the areas.

Figure 4. Algorithm of MONA (Vermulst *et al.*, 1998).



2.2.2 Model calibration and validation

Drainage density is one of the most important input parameters in modelling the hydrological top system within MOZART and NAGROM. In previous applications of MOZART and NAGROM, values for the drainage densities of the primary and secondary drainage systems were derived from different sources. Different GIS-databases for different regions have been compiled into two nation-wide GIS-databases, with drainage densities for the primary and secondary drainage system respectively. The reliability of these nation-wide GIS-databases varied for each region. Within the scope of the model applications for the Aquatic Outlook (Kors *et al.*, 1997), a model calibration was carried out based on the two GIS-databases with drainage densities mentioned above. Within that calibration, the drainage resistances of the tertiary drainage system and the wetted perimeters and specific ditch resistances of the primary and secondary drainage system have been optimised.

For the model application in the present study, new nation-wide GIS-databases with drainage densities for the primary and secondary drainage system have been used. For these GIS-databases (Top10-vector), densities of water courses of different classes of width have been derived from the 1:10000 topographical map of the Netherlands. Field surveys proved that the reliability of the Top10-vector databases is much higher than that of the original databases with drainage densities.

However, the first application of Top10-vector for the models resulted in considerably larger errors in computed groundwater levels than earlier applications, for example those for the Aquatic Outlook. Apparently, adapting the drainage resistances of the tertiary drainage system and the other calibration parameters mentioned above has compensated errors in the earlier used GIS-databases with drainage densities. As the observed errors in the computed groundwater levels were not acceptable, an additional calibration had to be carried out before using the models for the reference and climate scenarios.

In figure 5 and figure 6, the errors in the computed groundwater levels before calibration are presented. Figure 5 shows the errors in the computed mean highest groundwater levels, figure 6 shows the errors in the computed mean lowest groundwater levels. Both are calculated by taking the five most extreme values (highest or lowest) of the groundwater levels calculated per ten-day-interval. The errors in computed groundwater levels have been determined by comparing the model results with the 1:50000 soil map of the Netherlands, which includes area-covering information on groundwater regimes. This groundwater regime classification (GRC) includes the expected intervals of the highest seasonal groundwater levels and the lowest seasonal groundwater levels respectively. The intervals are expressed relative to surface elevations. The errors presented in figure 5 and figure 6 are the deviations of the computed mean highest and lowest groundwater levels outside the intervals given by the GRC-classification.

The additional calibration consisted of approximately 5 model runs of the coupled models MOZART and NAGROM. Within the calibration runs, the following input parameters of the models were optimised:

- drainage resistances of the tertiary drainage system;
- wetted perimeters of the primary and secondary drainage systems;
- specific ditch resistances of the primary and secondary drainage systems;
- drainage depths of the tertiary drainage system.

The deviations of the computed mean highest and lowest groundwater levels after the additional calibration are presented in figure 7 and figure 8. Especially the computed highest groundwater levels show a significant improvement. The mean lowest groundwater levels are determined by the regional hydrology (upward or downward seepage fluxes), rather than by drainage resistances and drainage depths, and show therefore less improvements. Despite the achieved improvements, the results are still far from optimal. Further improvements may be achieved by a more thorough calibration or by conceptual improvements of the groundwater models (for instance non-steady-state computations instead of steady-state computations with NAGROM). However, this was not feasible within this study.

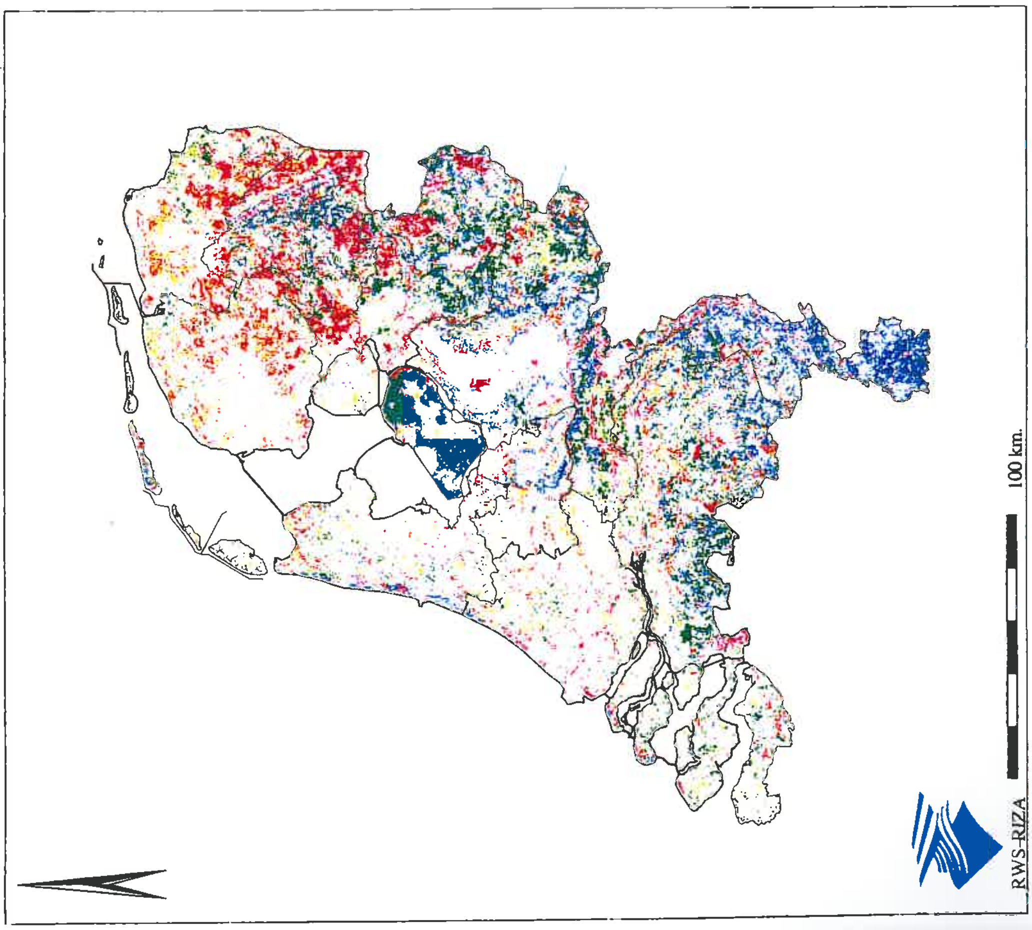


Figure 5. Deviations in computed mean highest groundwater levels, before calibration.

more than 1 m too low	0.00 –0.10 too high
0.5 –1.0 m too low	0.10 –0.25 m too high
0.25 –0.50 m too low	0.25 –0.50 m too high
0.10 –0.25 m too low	0.50 –1.00 m too high
0.00 –0.10 m too low	more than 1 m too high
no deviation	

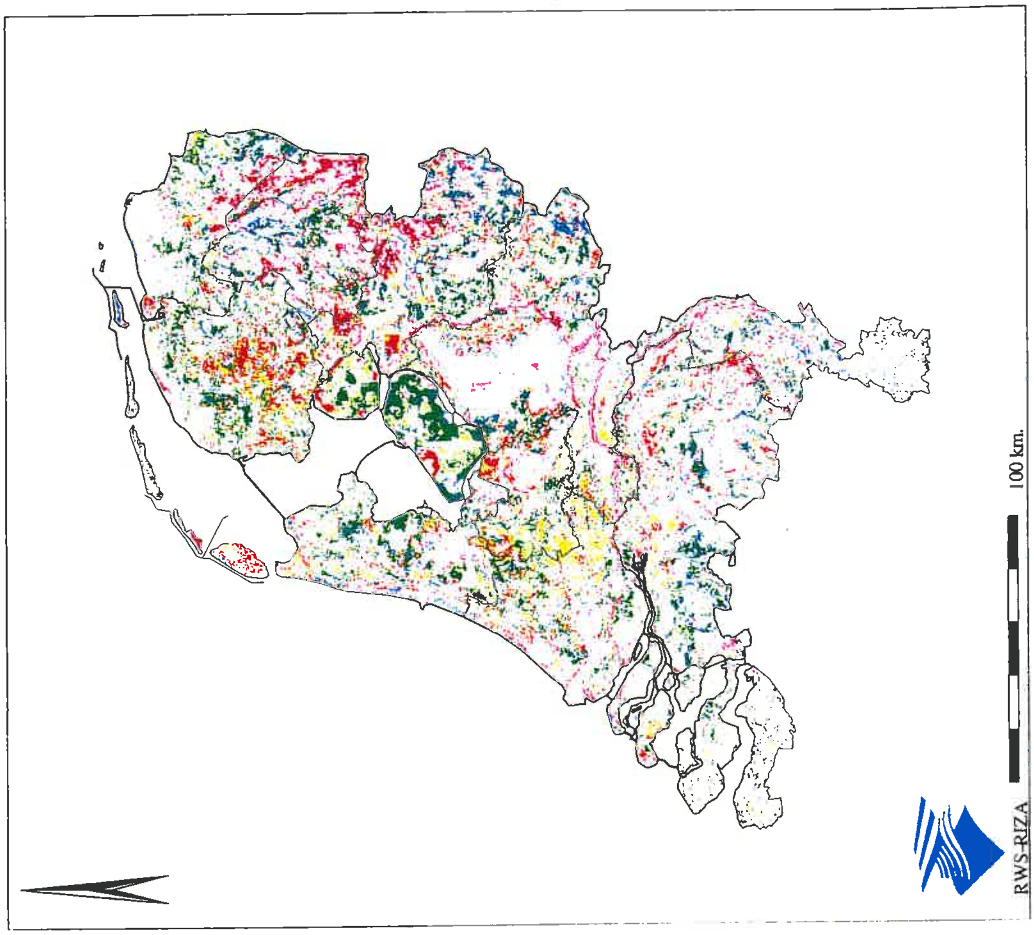


Figure 6. Deviations in computed mean lowest groundwater levels, before calibration.

more than 1 m too low	0.00 –0.10 too high
0.5 –1.0 m too low	0.10 –0.25 m too high
0.25 –0.50 m too low	0.25 –0.50 m too high
0.10 –0.25 m too low	0.50 –1.00 m too high
0.00 –0.10 m too low	more than 1 m too high
no deviation	

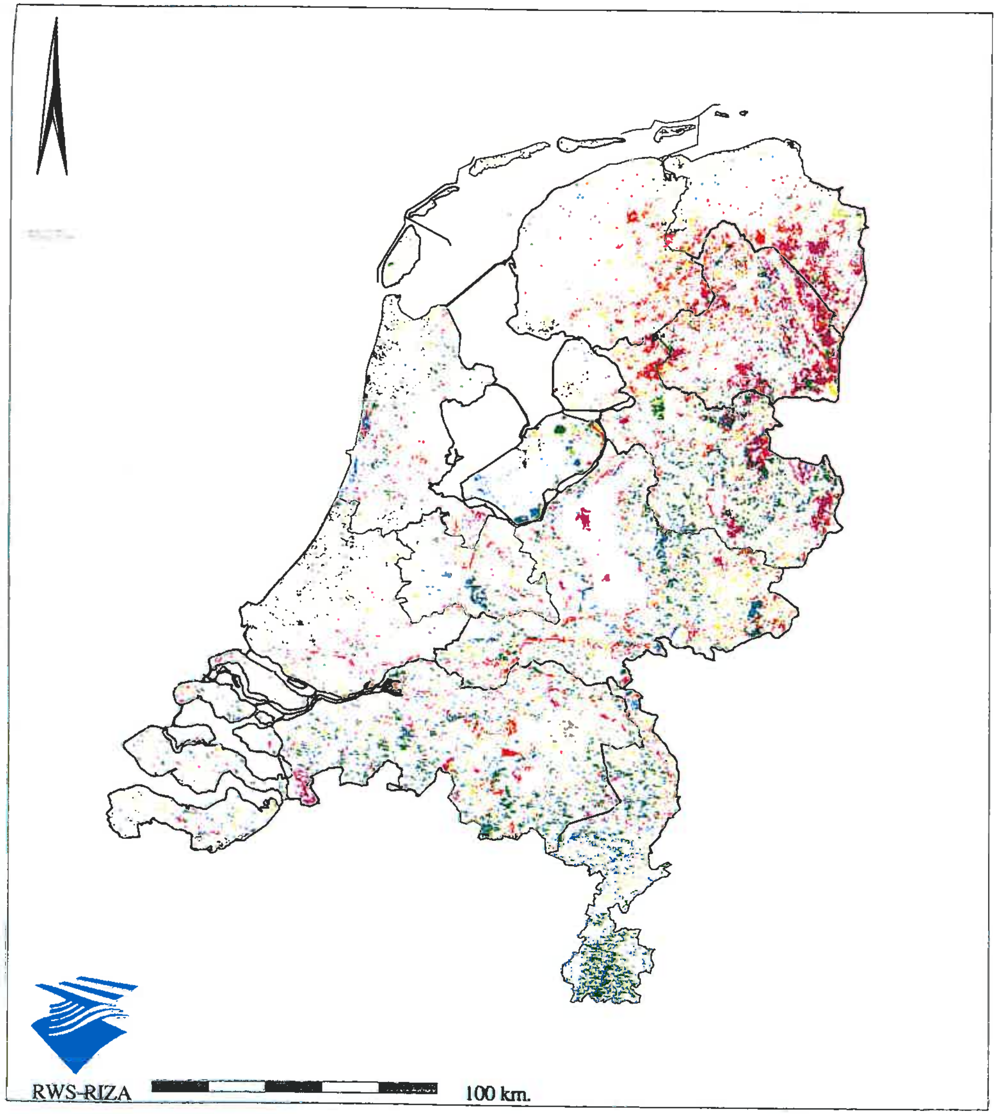


Figure 7. Deviations in computed mean highest groundwater levels, after calibration.

- more than 1 m too low
- 0.5 – 1.0 m too low
- 0.25 – 0.50 m too low
- 0.10 – 0.25 m too low
- 0.00 – 0.10 m too low
- no deviation
- 0.00 – 0.10 too high
- 0.10 – 0.25 m too high
- 0.25 – 0.50 m too high
- 0.50 – 1.00 m too high
- more than 1 m too high

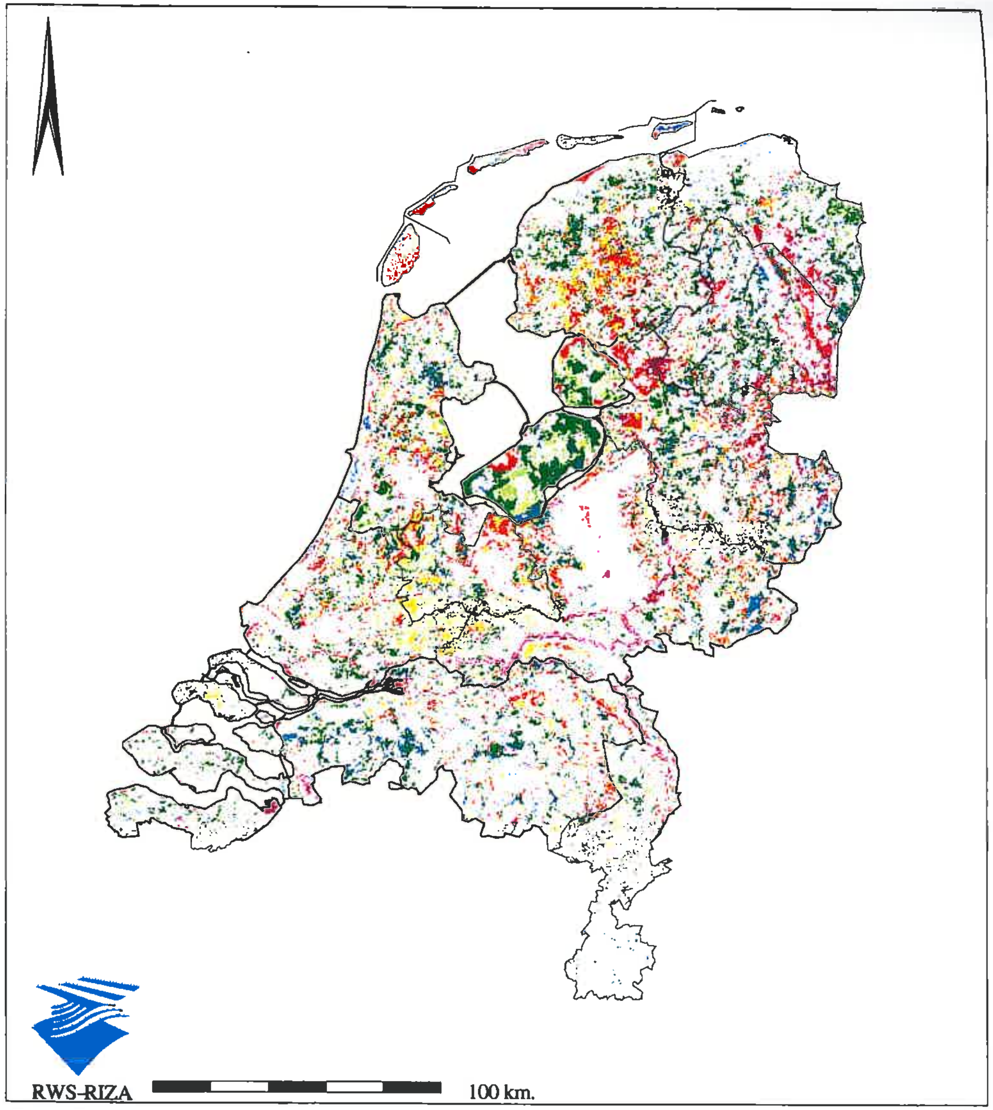


Figure 8. Deviations in computed mean lowest groundwater levels, after calibration.

- 0.5 – 1.0 m too low
- 0.25 – 0.50 m too low
- 0.10 – 0.25 m too low
- 0.00 – 0.10 m too low
- no deviation
- 0.10 – 0.25 m too high
- 0.25 – 0.50 m too high
- 0.50 – 1.00 m too high
- more than 1 m too high

2.3 Eco-hydrological model

The impacts of climate change on the vegetation of the wet terrestrial ecosystem have been estimated with the eco-hydrological model DEMNAT-2.1. This Dose Effect Model for terrestrial NATure (Witte, 1998) can be used to predict the impacts of hydrological changes on plant species richness of several terrestrial ecosystems. With DEMNAT-2.1 the following four hydrological changes (doses) have been considered: mean spring groundwater level, upward seepage, surface water level of small lakes and the amount of externally supplied water. Within this study, the hydrological changes are derived from the results of the calculations with the hydrological models described in the previous sections. The ecological effects are expressed as changes in the botanical quality (completeness) of eighteen ecosystem types (ecotopes) for a grid of 1×1 km^2. In addition, the effects may be weighed according to the importance of the ecotopes for nature conservation in the Netherlands to determine the impact on nature conservation in terms of nature values.

DEMNAT contains three essential modules: (1) geographical schematisation of ecosystems on a nation-wide scale, (2) a set of dose-effect functions and (3) a conservation valuation module. The schematisation module is used to retain units (ecoplots) that can be regarded as homogeneous in their reaction to hydrologic changes (doses). The module uses so-called dose-effect functions to predict the changes in species richness of the ecosystems. The conservation valuation module sums the changes in species richness to calculate conservation value for each square kilometre. The three modules will be described in more detail below.

Geographical schematisation module

To determine a schematisation of the groundwater-dependent ecosystems DEMNAT combines geographical information on hydrology, soil and vegetation. The abiotic part of DEMNAT is schematised by ecoserie-types (Klijn *et al.*, 1996). The ecoserie-types are based on features of the soil, groundwater level and groundwater quality, derived from a map with soil units and a map with groundwater classes (both 1:50000). It is possible that several ecoseries-types occur within one gridcell. They contribute to the determination of the spatial units and the changes of site factors due to the hydrological changes.

DEMNAT distinguishes the following site factors: soil moisture regime, nutrient availability, acidity and salinity. The relationship between site factors and vegetation is described with the ecotope classification system of Witte and van der Meijden (1990) in the ecosystem types. This ecosystem typology describes the vegetation in relation to site factors, which influence the vegetation directly. For DEMNAT the ecotope types are clustered to the eighteen ecotopes, described in table 2. A combination of vegetation structure (the first letter) and site classes (the two numbers) code an ecotope.

To each ecotope a number of characteristic plant, species have been assigned, based on their preference to site factors and vegetation structure. The present distribution of ecotopes is derived from the national database on flora, FLORBASE (Van der Meijden *et al.*, 1996), which contains information on the presence of plant species within a gridcell of 1×1 km^2. Finally, the degree of presence of ecotopes is expressed in terms of 'completeness'. The completeness indicates the relative plant species diversity of a certain ecotope and is determined by adding indicator values of the species characteristic for that ecotope into a score. The indicator values indicate to which extent a plant species is characteristic for a certain ecotope. This score is than normalised to an index of completeness (1 indicates very well developed in terms of botanical respect and at 0 the ecotope type is absent or indicates not enough information on indicative plant species).

Table 2. Description of the eighteen ecotopes used in DEMNAT-2.1.

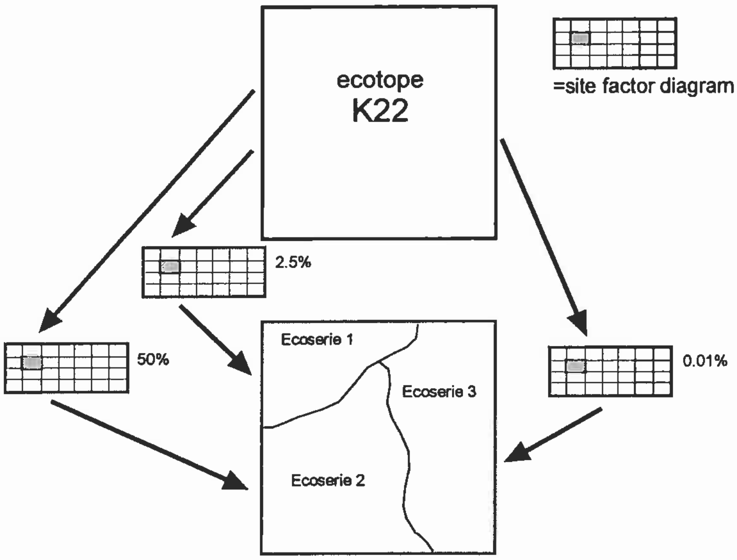
Ecotope	Description
A12	(Semi-)aquatic vegetation of nutrient-poor weakly acid waters
A17	(Semi-)aquatic vegetation of moderately nutrient-rich waters
A18	(Semi-)aquatic vegetation of very nutrient-rich waters
bA10	(Semi-)aquatic vegetation in brackish water
K21	Herbaceous vegetation of wet, nutrient-poor, acid sites
K22	Herbaceous vegetation of wet, nutrient-poor, weakly acid sites
K23	Herbaceous vegetation of wet, nutrient-poor, alkaline sites
K27	Herbaceous vegetation of wet, moderately nutrient-rich sites
K28	Herbaceous vegetation of wet, very nutrient-rich sites
bK20	Herbaceous vegetation of wet, brackish sites
bK40	Herbaceous vegetation of moisture, brackish sites
K41	Herbaceous vegetation of moisture, acid sites
K42	Herbaceous vegetation of moisture, nutrient-poor, weakly acid waters
H22	Woody vegetation of wet, nutrient-poor, weakly acid sites
H27	Woody vegetation of wet, moderately nutrient-rich sites
H28	Woody vegetation of wet, very nutrient-rich sites
H42	Woody vegetation of moisture, nutrient-poor, weakly acid sites
H47	Woody vegetation of moisture, moderately nutrient-rich sites

Table 3. The site factor diagram, used within DEMNAT.

	Fresh water					brackish	saline
	nutrient acid	poor weakly acid	alkaline	moderately nutrient rich	very nutrient rich	water	water
aquatic		A12		A17	A18	bA10	
wet	K21	K22, H22	K23	K27, H27	K28, H28	bK20	
moist	K41	K42, H22		H47		bK40	
dry							

The method, described above is used, to determine the occurrence of ecotopes per square kilometre. Because the ecoserie-types determine the impact of the hydrological changes, it is important to know on which ecoserie(s) within a certain gridcell the ecotope occurs. Dependent on the development of the different site factors, known for a certain ecoserie, the probability that a certain ecotope occurs on that ecoserie is determined (figure 9). This chance is derived with so-called site factors diagrams (table 3). For every ecoserie, a site factor diagram is specified. A combination of an ecoserie and an ecotope is called an ecoplot. These are the actual units where the calculations are carried out.

Figure 9. Schematization for DEMNAT. Coupling information on ecotope K22 to different ecoserie types occuring within a kilometre square (Bos *et al.*, 1997).



The hydrological changes are allocated to the ecoserie-types using weighing factors. The four doses are derived from the hydrological models. With the linking tool, MODEM, the hydrological changes are translated to doses for input for DEMNAT.

Dose-effect functions

DEMNAT predicts the impact of the hydrological changes for the wet terrestrial vegetation with dose-effect functions. These functions reflect an empirical relation between the hydrological changes and the changes in completeness of vegetation. Within these functions, it is assumed that it takes longer for the vegetation to recover than to deteriorate (figure 10). For every hydrological doses, combination of ecotope and ecoserie a dose-effect function is known. The functions describe the ecological impact of the hydrological doses ecotopes and are made through expert judgement. One dose may change more than one site factor. A rise of the groundwater level may influence for example the intensity of mineralisation processes and thereby the nutrient availability and off course the humidity of the soil.

Figure 10. Dose-effect functions used to compute deterioration and restoration of ecotopes in terms of specifuc biodiversity (-) due to changes in mean spring groundwater level (MSGL), (Bos *et al.*, 1997).

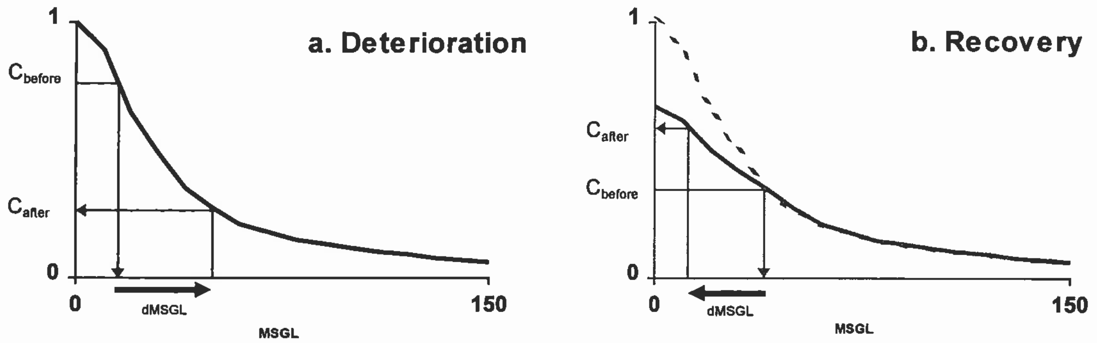
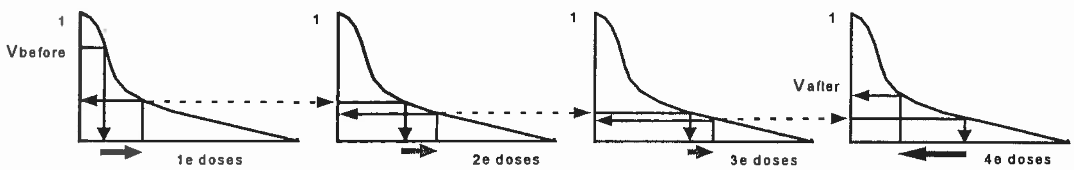


Figure 10 shows how a change of a dose (in this case mean spring groundwater level) leads to a change of the specific biodiversity of an ecotope. With DEMNAT the summed effect of the four doses can be determined. In this example first, the present groundwater level is derived from the specific biodiversity of the ecotopes in the present situation (input). Then the specific biodiversity after the scenario is determined, by following the change of the doses predicted by the hydrological models. First the dose, which causes the most damage, is used, then the one with the second most damage and so on. The specific biodiversity after the first doses is the specific biodiversity when determining the impact of the second doses (figure 11).

Figure 11. The determination of the impact of the four hydrological doses on the specifc biodiversity (Bos *et al.*, 1997).



Conservation valuation module

Besides the change of the specific biodiversity of the eighteen ecotopes, the impact of the hydrological changes may also be expressed as the change of conservation value. This makes it possible to superimpose ecological effects and to compare different scenarios. To determine the conservation value two principles are used within DEMNAT: (1) more rare ecotopes have a higher conservation value and (2) expansion of an ecosystem is always positive. The change in conservation value is determined by multiplying the completeness with the corresponding potential conservation value. Figure 14 shows the present conservation values of wet terrestrial ecosystems, based on the presence of plant species in FLORBASE and the nature valuation module. However, this map shows systematic errors due to differences in survey-activity. For example in the province Friesland large areas are empty, despite the occurrence of nature reserves.

2.4 Agricultural cost model

In this survey the AGRIcultural COst Model, AGRICOM, is used to consider the effects of the hydrological changes caused by climate change and land subsidence on costs and benefits for agriculture in the Netherlands. This section gives a short description of AGRICOM. RIZA (1995) described the model in more detail.

The calculations of AGRICOM are based on the results of calculations with the hydrological model MOZART. MOZART gives information of e.g. the amount of sprinkling needed, crop damage, crop yield and the groundwater levels. These values are calculated for every decade. AGRICOM uses this information together with e.g. information on costs for sprinkling, the sprinkling type used, relations between the mean lowest groundwater level and the mean highest groundwater level on one hand and drought or water logging damage on the other hand, to calculate the yield loss for each plot of 500x500 m. The yield loss is the difference between the maximum potential yield, which is the yield at ideal hydrological conditions, and the actual yield which is also affected by drought or water logging. Using the results from MOZART and information on the regional water system, AGRICOM considers the following modules to calculate the costs and benefits for agriculture:

- sprinkling costs (fl) (A),
- physical crop yield (kg/ha) (B),
- crop value (fl) (C),
- mean reduction fraction of the crop yield (D),
- mean crop yield (E).

Figure 12. Concept of AGRICOM RIZA (1995).

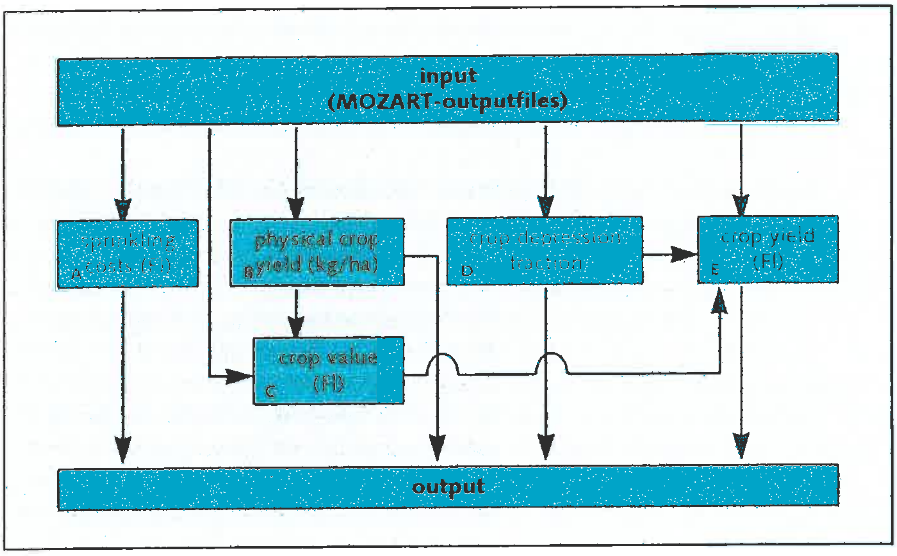


Figure 12 gives a flowchart of the interactions between the modules. This figure shows that AGRICOM contains two types of calculation: one calculating the sprinkling costs (module A) and one calculating different types of agricultural damage (modules B, C, D and E). The agricultural damages can be derived in two ways: using (1) the modules B and C or (2) the modules D and E. The first method is still in development. Within AGRICOM, the following crops have been distinguished: grass, cereals and other agriculture.

Determination of sprinkling costs

Water for crop irrigation is obtained by pumping either from a nearby source of surface water (a ditch or canal) or from a groundwater well. To calculate the sprinkling costs, AGRICOM considers invariable and variable costs. The variable costs (Dfl/mm) consist of the costs for labour (not included in this study) and energy. The invariable sprinkling costs consist of investments in sprinkling installations and depend on the type of sprinkling and the pump capacity, and the yearly costs for insurance and reparations. The sprinkling system depends e.g. on the crop type, area and source of the sprinkling water. All these factors are considered for each plot. The total costs of sprinkling per plot equal the invariable costs multiplied by the area of the plot plus the amount of sprinkling per plot (mm) times the variable costs. With the used version of AGRICOM, the sprinkling costs can be determined on a national scale.

Determination crop damage

AGRICOM considers three types of crop damage:

- Drought damage: the reduction in crop production due to water shortages.
- Water logging damage: damage caused by excessive wet conditions, due to water logging and inundation.
- Salt damage: the reduction in crop production to excessive salt concentration of the water in the root zone.

As mentioned before AGRICOM contains two methods to derive the agricultural damage. One is based on the so-called survival fractions per decade, calculated by MOZART. The other is based on the groundwater levels per decade calculated by MOZART and IKC-tables (IKC, 1993). These methods are explained below.

Determination of damage using survival fractions

Every time-step MOZART estimates the fraction of the total crop production that is lost due to salt, drought and water logging damage and the cumulative damage, so-called damage fractions. These are parts of the crop that will not be produced. The drought damage fraction is defined as the fraction of the crop damaged because of drought. It depends on the ratio of the actual and potential evapotranspiration and the growing season. The latter takes into account that crops cannot be damaged outside the growing season and that some crops have drought sensitive periods with more severe damage. The salt damage depends on the salt concentration in the root zone and is independent from the growing stage of the crop. MOZART has the possibility to consider two kinds of damage caused by excessive wet conditions: water logging damage and inundation damage. The first is derived from the ratio between the actual and potential evapotranspiration. Consequently, it depends on crop type and growing stage. Inundation damage can only be considered within MOZART, when it is linked to the distribution model (Wegner, 1981).

The cumulative damage is carried forward from one time-step to the next, expressed as the so-called survival fraction. The survival fraction is defined as the fraction of the crop that is left after the damage, and equals therefore the complement of the total cumulative damage fraction (1 minus the cumulative damage fraction). Because the production is variable over the year, for every time step the potential yield fraction is used. This is the part of the production that may still be produced that year (the remaining yield), assuming no damage occurs. Grass, for example, grows continuously over the year. Half way the year, half of the total potential production may be produced. Consequently, only half of the production can be damaged. Finally, MOZART calculates the total crop yield damage fraction, based on the survival fraction and the remaining yield. AGRICOM then calculates the annual actual physical crop yield, by multiplying the annual potential physical crop yield with the cumulative damage derived from MOZART (module B).

In module C the crop damage is estimated in terms of money, using the crop value. The crop value (also module c) depends on the total amount of crop produced. For example in dry periods the crop prices may rise, due to the scarcity of the products. Crop prices depend therefore on the total crop yield from the calculated year.

Determination of damage using crop yield depression fractions

The crop damage may also be derived using the crop yield depression fractions and crop values in terms of money. The depression fractions used are, in contrast to the damage fractions used for the calculations of the physical crop yield, not derived from MOZART. In module D, AGRICOM calculates the damage fractions based on the groundwater levels calculated by MOZART and IKC-tables (IKC, 1993). Using the groundwater levels calculated by MOZART, AGRICOM computes the mean lowest groundwater level (MLGL) and the mean highest groundwater level (MHGL) for each plot. When the MHGL and MLGL is known for a specific plot, the corresponding crop damage is determined from the IKC-tables. The IKC-tables contain the relation between drought and water logging damage for different combinations of MHGL and MLGL for different crop and soil types. For some crops it is also taken into account whether they are sprinkled or not. In addition, drought damage depends on the climate zone in the Netherlands. In the IKC-tables, the drought and water logging damage are expressed in terms of money but they may also be used to determine the physical depression yield in kg (RIZA, 1997).

Finally, in module E, the long-term mean crop yield in terms of money is determined, based on the long-term mean yield depression fractions for drought or water logging damage and the crop value for the calculated year. The crop values used in this study are mean values expressed in fl/ha, derived from results of an agronomic study (Hoogeveen *et al.*, 1996).

The damage caused by excessive wet conditions is not yet well implemented in MOZART and is being developed. Using the method of survival fractions, only drought damage and salt damage can be determined. Therefore the method, using the IKC-tables as described below, is used to calculate the agricultural damages.

3 Scenarios

To assess the impact of climate change a comparison has been made between a situation without changed climate conditions and a situation with changed climate conditions. This section gives a description of these situations. The scenarios without climate change are referred to as reference situations on which the climate scenarios are projected. Middelkoop *et al.* (1997) described the reference situations in more detail. The used climate scenarios are based on results of General Circulation Models. The IPCC concludes that the expectations for areas the size of Europe can not be derived from these models. Therefore, the scenarios should be used to get an idea of the impacts if the climate changes according to a specific scenario (what-if scenario). They should not be seen as a prediction of the future.

This chapter gives a description of the scenarios and the corresponding boundary conditions used to estimate the impact of the autonomous developments and climate change. In addition, the assumptions made for the different scenarios are described. These assumptions include: soil subsidence and land use changes for the reference scenarios and changes in evapotranspiration, precipitation and sea level rise for the climate scenarios. The scenarios representing the present situation, the autonomous developments, central estimate for 2050 and the upper estimate for 2100 are referred to as respectively REF1995, REF2050, CEN2050 and UPP2100.

3.1 Reference scenarios

To define the impact of climate change, two reference situation have been considered:
1. the present hydrological situation (REF1995),
2. the hydrological situation for 2050 including autonomous developments (REF2050).

3.1.1 Present hydrological situation: REF1995

The present situation, REF1995, includes the present situation of the water system and management in the Netherlands. It is used to get an indication of the autonomous developments and climate changes that may occur in the next century for the regional water systems. In this study, the regional water system is defined as the fresh water system except the major rivers and the IJsselmeer area. All water courses in the urban and rural areas, small lakes and groundwater are included. The area can be subdivided in higher areas with Pleistocene deposits in the eastern and southern part of the Netherlands and polder areas with Holocene deposits in the northern and western part (figure 13).

In the higher Pleistocene areas, almost the entire precipitation surplus is drained by gravity. Therefore, the position in the hydrological system is important.

Groundwater flow occurs between areas with infiltration and upward seepage. Dry conditions occur mostly in the infiltration areas, which are sandy ridges, while wet conditions take place in the areas with upward seepage which are the valleys between the ridges. In these brook valleys, the conservation values are high, according to the present ecological values in DEMNAT (figure 14). The dryer conditions in the sandy areas result in a higher drought damage for agriculture in these areas. Discharges occur by natural courses by brooks and small rivers. Ditches, canals, trenches and artificial drains are used to improve the discharge in wetter areas.

The western and northern parts of Netherlands are polder areas. In these low-lying areas, water levels are maintained by pumping the precipitation surplus and seepage water into storage canals. From there, it is discharged into the rivers Rhine, Meuse, Lake IJsselmeer or the sea. Surface water levels are maintained within narrow ranges. In times of drought, Rhine water is used to supply the polders with sufficient water. Because of the low drainage resistances, there is an intensive interaction between groundwater and surface water. Consequently, groundwater levels are determined by the different surface water levels in adjacent polders, rather than by differences in elevation. Strong fluxes occur between the areas with reclaimed lakes and the cultivated peat areas. However, in some cases the upward seepage has a minimal effect on the groundwater level due to the high drainage capacity. When the upward seepage consists of brackish water, Rhine water is used to flush salt loads. This may decrease the botanic quality of the vegetation.

In the Holocene part of the Netherlands, the highest conservation values occur in the cultivated peat areas and dune areas. In these parts, also the wet areas with the highest water logging damage for agriculture occur (figure 15).

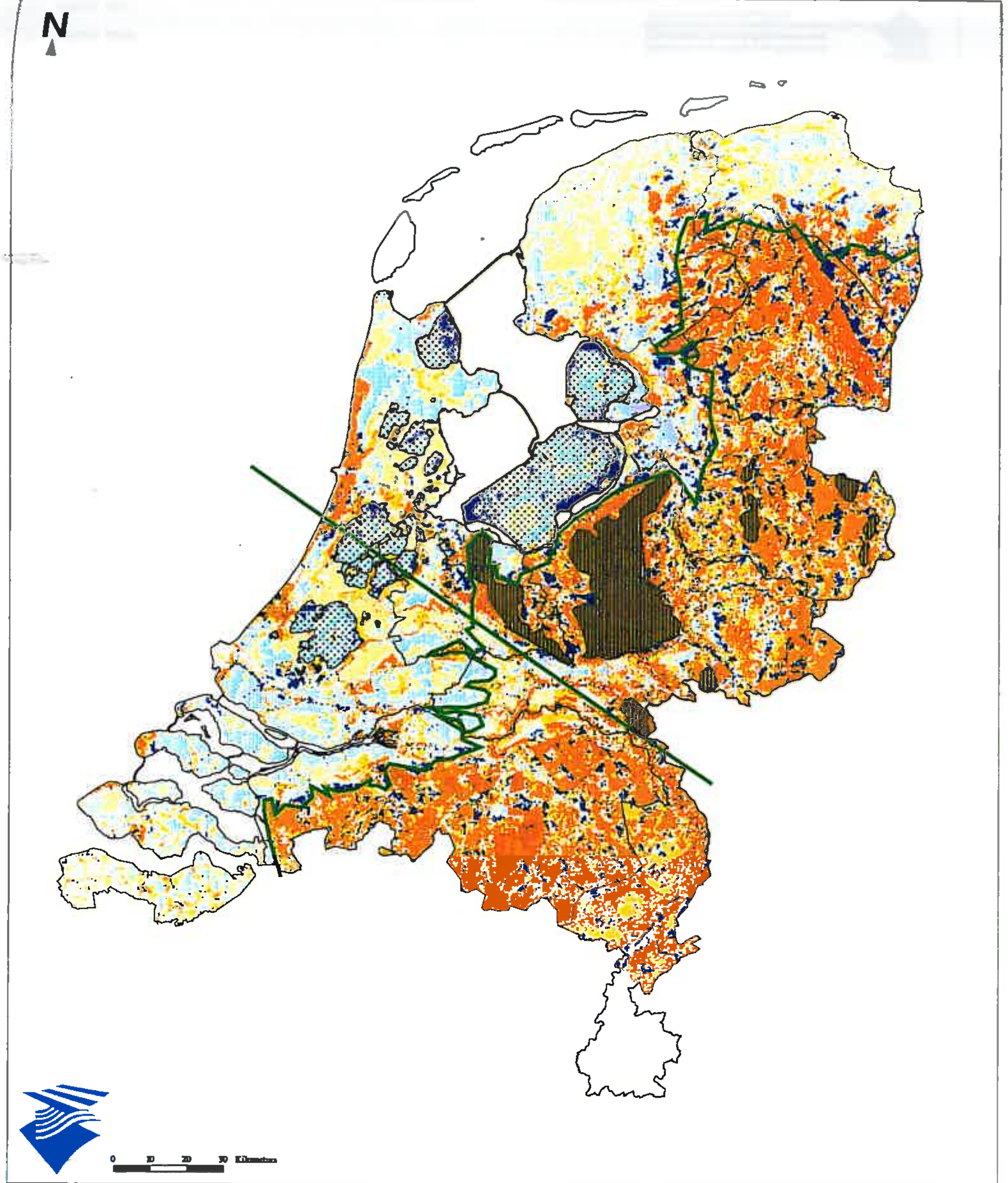


Figure 13. Upward and downward seepage fluxes in the Netherlands. Main geomorphological features of the Netherlands.

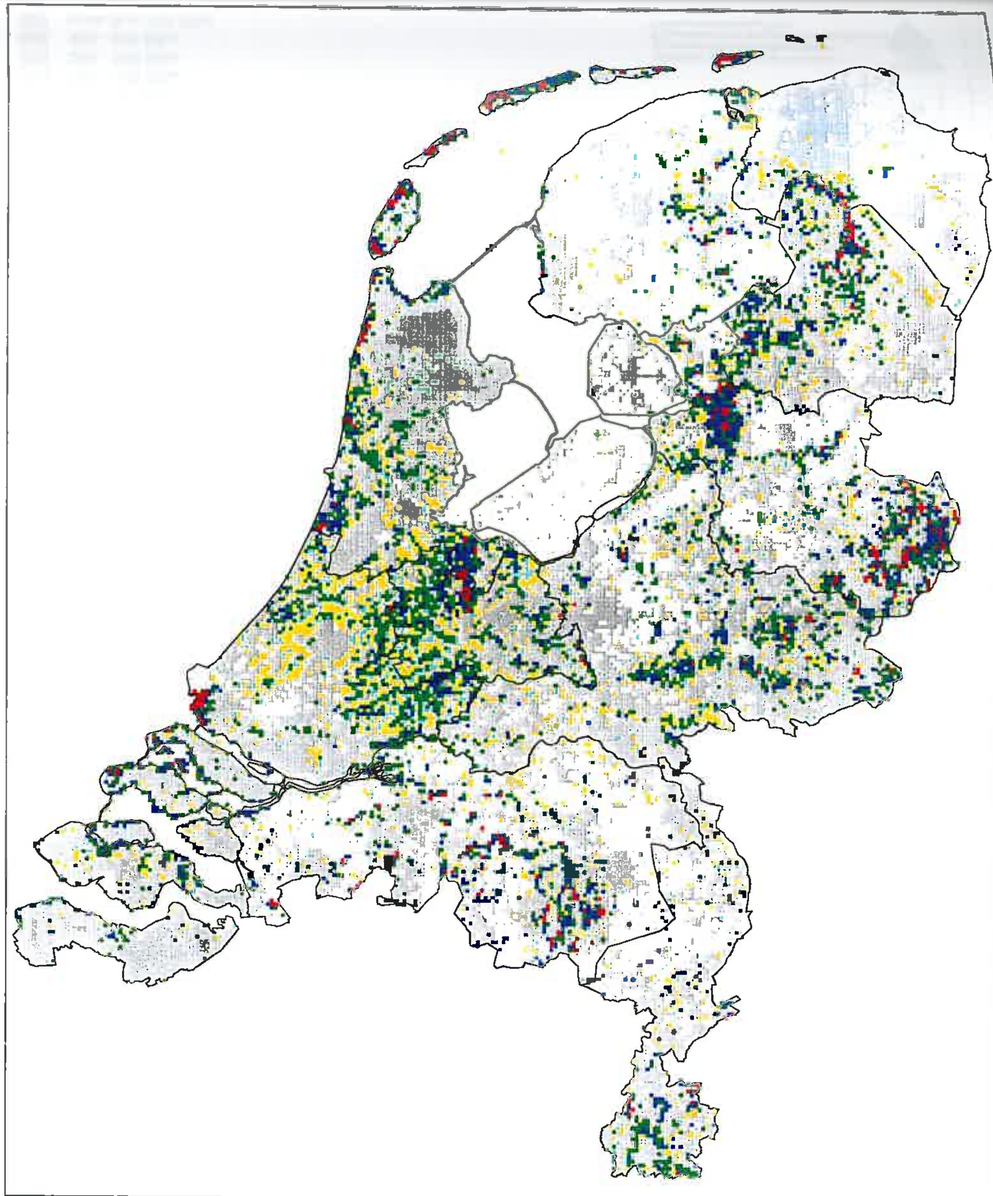


Figure 14. Present ecological values of wet terrestrial ecosystems in the Netherlands.

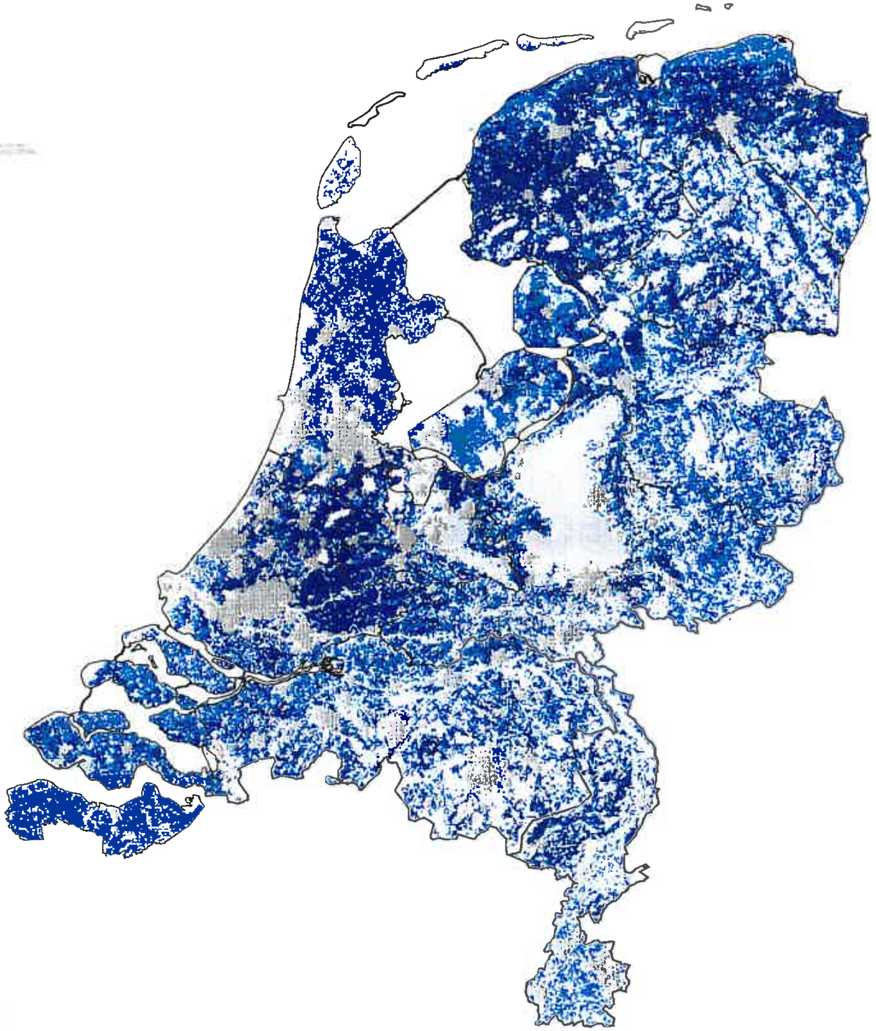


Figure 15. Present water logging damage in the Netherlands.

- 0 - 25 fl/ha
- 25 - 100 fl/ha
- 100 - 200 fl/ha
- 200 - 300 fl/ha
- 300 - 400 fl/ha
- more than 400 fl/ha
- nature area

0 20 40 60 Kilometers

N

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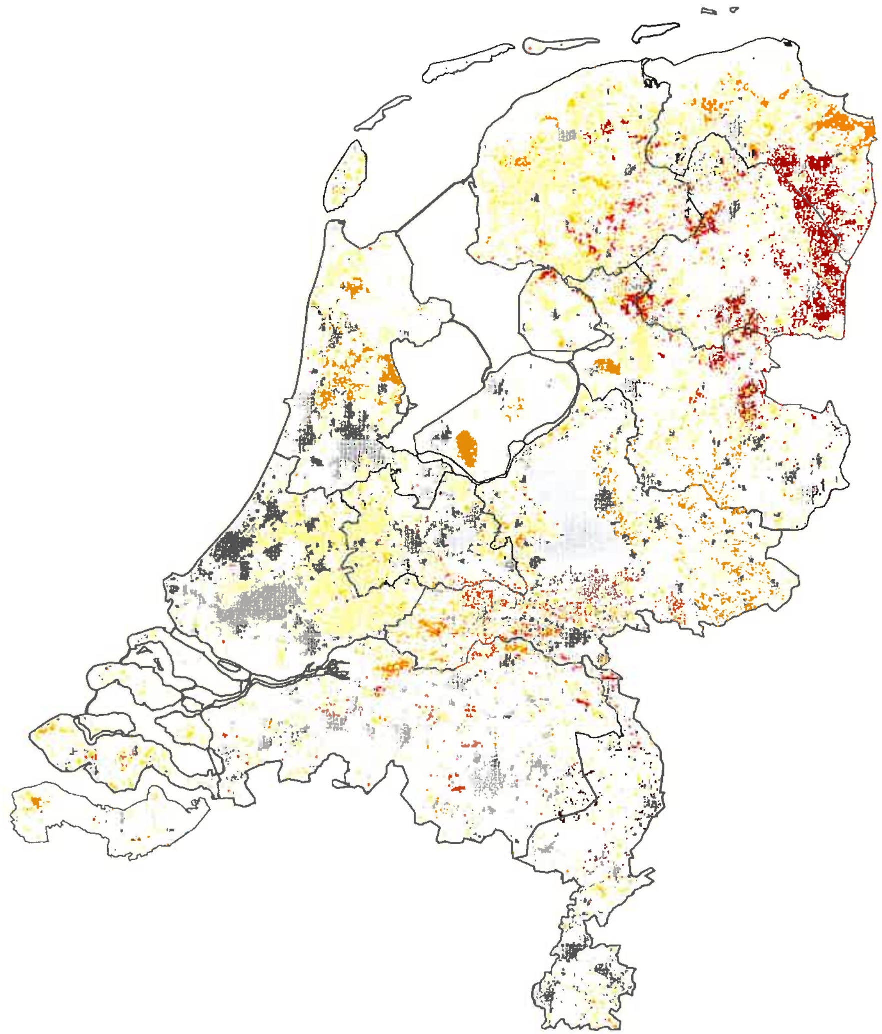

Figure 16. Present drought damage in the Netherlands.

- nature area
- urban area
- 0 - 25 fl/ha
- 25 - 100 fl/ha
- 100 - 200 fl/ha
- 200 - 300 fl/ha
- 300 - 400 fl/ha

0 20 40 60 Kilometers

N

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3.1.2 Hydrological situation in 2050: REF2050

The reference situation 2050 reflects the state of the water systems in the Netherlands for the year 2050 without changed climate conditions, but including the effects of different autonomous (socio-economic) developments. It is based on existing scenarios for future water management and extrapolated trends in water management in the Netherlands (Projectgroep Watersysteemverkenningen, 1996) and studies on socio-economic developments (CPB,1992). Autonomous developments are developments that affect the water system and may occur independent from climate change. Examples are nature restoration, changed strategies in the management of water levels of the lake IJsselmeer and changes in land use.

The most important developments are land subsidence, changes in land use and the autonomous sea level rise. Only these expected developments are taken into account, because of the reasonable estimate that can be made and because of the influence on the hydrological situation. Other autonomous developments may have a considerable influence on hydrology as well, but these are too uncertain for a reasonable estimate and have therefore not been taken into account. Some autonomous developments will however not be strictly autonomous, since their implementation may depend on the climate changes.

3.1.2.1 Change in land use

Only the developments in land use until the year 2015 have been included. Land use changes after 2015 are very uncertain and were therefore not taken in account. In this study, the changes in land use according to European Renaissance scenario (CPB, 1992) are assumed to take place. Middelkoop *et al.* (1997) concluded that this would be the most realistic alternative for trends in land use.

The changes in land use were based on the LGN2 databank of land use. Projectgroep Watersysteemverkenningen (1996) describes the derivation of these spatial changes in more detail. Different socio-economic scenarios, defined by CPB (1992), have been translated to changes in the distribution of land use. Subsequently, for each socio-economic scenario, the predicted changes in land use have been allocated. Within the reference and climate scenarios, the changes in land use according to the European Renaissance scenario are assumed to take place. The area of agriculture will decrease with 6.7% (2300 km^2) and the nature area and urban area will increase with approximately 3.9% (1500 km^2) and 1.9% (700 km^2) respectively (table 4). Also, an area of combined nature and agriculture of approximately 310 km^2 is foreseen.

The final result has been compared to the databank, 'the new map of the Netherlands', which contains about 3000 rural plans that may be realised by 2005. Examples are plans for infrastructure, residential areas, business, recreation and development of nature. The categories agriculture and urban area show approximately the same increase in area according to 'the new map of the Netherlands' and the European Renaissance scenario. However, 'the new map of the Netherlands' exhibits a slighter increase of the area of nature (30% against 68% according to European Renaissance).

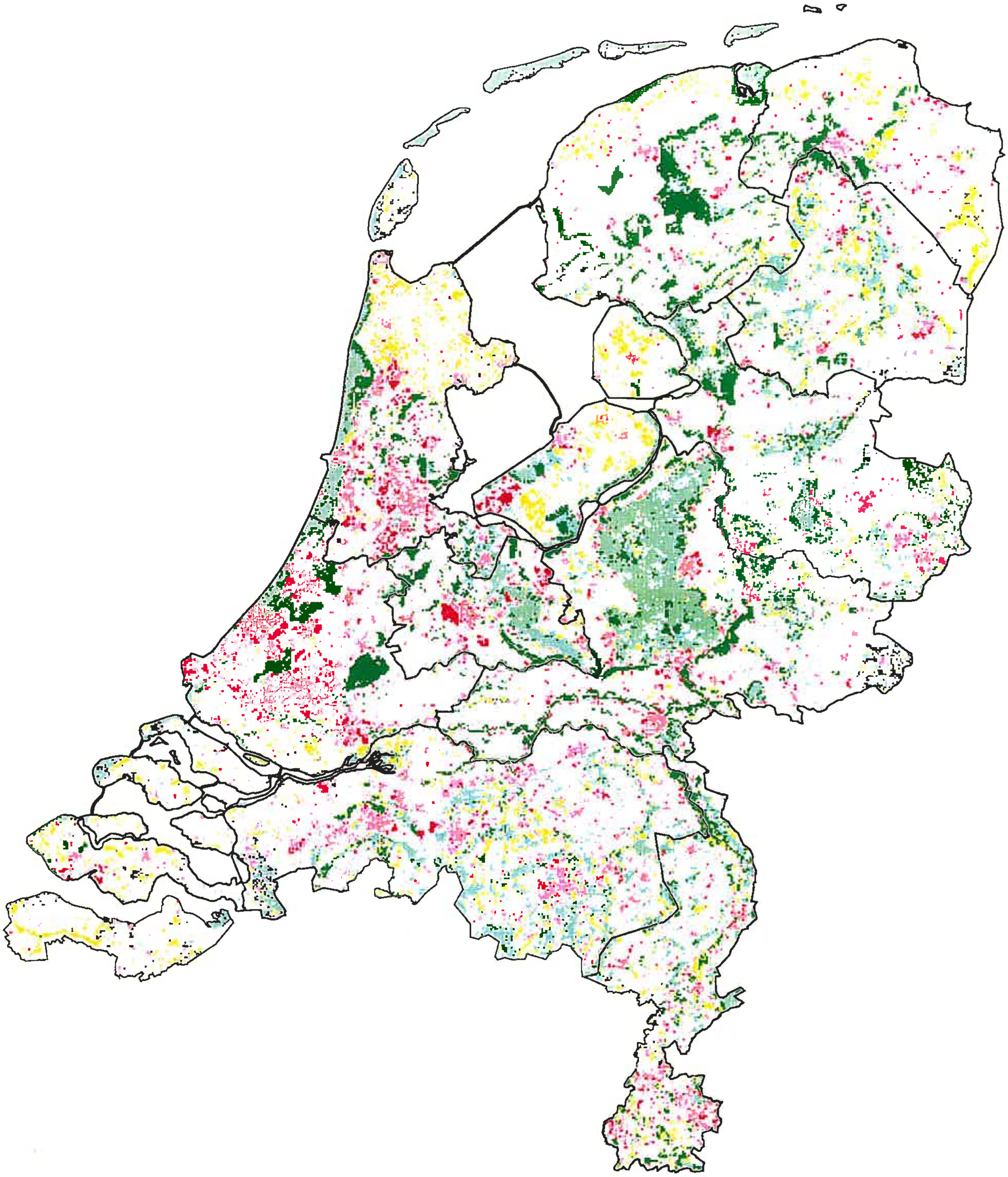

Figure 17. Changes in land use according to the European Renaissance scenario.

- no change
- urban area
- new urban area
- nature
- new nature
- agriculture replaced by other agriculture

0 20 40 60 Kilometers

N

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'The new map' seems to give a more realistic prediction, but the categories contain insufficient information on the kind of land use. Consequently, translation of the legend units of the 'new map' to crop characteristics, such as crop factors (input parameters for MOZART), was not possible. Therefore, the predicted changes in land use from Watersysteemverkenningen (1996) have been used to account for socio-economic developments in the reference and climate scenarios. These changes in land use are the upper boundary of MOZART and NAGROM because it affects the evapotranspiration.

Table 4. Distribution of land use for the present situation 1995 and estimates for 2015 (%).

Scenario	agriculture	nature	urban areas	other land use
Present situation (REF1995)	55.8	12.2	7.6	24.4
Central estimation for 2015 (CEN2050)	49.1	16.1	9.5	25.3

3.1.2.2 Land subsidence

Another autonomous development is land subsidence. This is one of the autonomous developments that will have a significant influence on the water management of the Netherlands. Photo 1 gives an example of the effect of land subsidence in urban areas. The entry of the church used to be at the same height as the street, but land subsidence has lowered the street in respect to the church.

Within the REF2050 and the climate scenarios, drainage levels have been adapted to the estimated land subsidence rates. The three major causes of land subsidence in the Netherlands are:

- oxidation and settlement of Holocene deposits, especially peat soils, due to intensified drainage conditions;
- mining activities, especially those of gas;
- tectonic movements.

The effects of the different types of land subsidence have been quantified for the year 2050 and the effects have been summed to a predicted overall land subsidence for 2050. For 2100, the subsidence is predicted by extrapolating the results of land subsidence for 2050.

Oxidation and settlement

Oxidation is the mineralisation of organic matter in the top layer of especially peat soils, whereas settlement is the consolidation of peat and clay layers as a result of lowered piezometric heads. Both processes are reinforced by the lowering of groundwater tables, for example as a result of intensified drainage or the reclamation of adjacent shallow lakes. Since the cultivation of most peat soils in the polder areas, in the late Middle Ages, oxidation and settlement have caused a land subsidence of about 3 metres. Subsidence has been stronger in peat soils than in clay soils. During the last decades, drainage conditions in many polder areas have been improved for agricultural purposes, which resulted in a reinforcement of oxidation and settlement. At the moment, land subsidence amounts up to 1 cm per year in some peat areas.

Photo 1. Example of impacts of land subsidence. The top of the stone wall indicates the former surface level.

The land subsidence caused by oxidation and settlement of Holocene deposits is influenced by soil structure and groundwater table. For example, the subsidence has been stronger in peat soils than in clay soils. With a lower groundwater table, more oxygen intrudes into the soil and therefore aeration and oxidation of the soil is stronger. In addition, soil organisms can develop better if there is more oxidation in the soil, which enforces the process of oxidation further. Estimates of the rate of oxidation and settlement were derived by combining soil physical information with information on drainage depth.

Provincie Friesland (1997) gives land subsidence rates as a result of oxidation and settlement for different combinations of soil type and drainage depth (see Appendix 1). The soil physical units used as input for MOZART have been translated to the soil types used by Provincie Friesland (1997). Using this translation key and combining it with information on drainage depths used as input for MONA, a nation-wide map has been compiled with land subsidence rates due to oxidation and settlement. For three soil physical units, the translation resulted in unrealistic land subsidence rates. For these soil physical units, land subsidence rates have been adapted based on field experience of district water boards.

In general, nature reserves have high drainage levels, resulting in wet conditions and minimal aeration of the soil. Therefore, it was assumed that oxidation and settlement are negligible within nature reserves. Using the LGN2 land use map, nature reserves have been excluded from other rural areas.

Multiplying the obtained intensity for land subsidence (meter per year) with the number of years for which the land subsidence will be observed, the land subsidence has been derived. It was assumed that the drainage level would be maintained. This assumption may not be true in all areas. Present water management policies tend towards more sustainability and therefore towards higher maintained surface water levels in order to restrict land subsidence. Therefore, the presented land subsidence predictions might be overestimated in some areas.

The thickness of the deeper peat layers of the soil has not been taken into account, because this information is not available on a nation-wide scale. This may also give an overestimate of the land subsidence because it can be assumed that the soil subsidence by oxidation and settlement of Holocene deposits will stop when the thickness of peat is reduced to about 25 cm.

In the polders of Southern Flevoland, which are only 25 year old, stronger land subsidence occurs due to the riping process of the soil. This riping process will probably finish before the year 2100. Likewise, the predicted land subsidence for 2050 can be considered as realistic. Estimates for 2100, which are an extrapolation of the estimates of 2050, may exaggerate the effect of the riping process. However, this effect will not influence the results due to the present modelling approach.

Tectonic movements and mining activities

Mining activities are a second cause of land subsidence. The most important mining activities are those of gas in the northern Groningen and Friesland provinces. For the year 2050, land subsidence figures up to 35 cm are foreseen. The third and least important cause of land subsidence are tectonic soil movements.

Figures for the effect of tectonic movements on land subsidence were obtained by interpolating 40 measure points funded on Pleistocene deposits (Lorenz, 1991). Northwestern areas of the Netherlands exhibit a tectonic lowering of up to 5 cm in 2050, whereas southeastern areas exhibit a tectonic rise of up to 5 cm in 2050. The land subsidence caused by mining activities originates from data from the NAM.

In order to get an overview of land subsidence rates, the different effects have been added. This predicted land subsidence for 2050 is presented in figure 3. For 2100, the subsidence is predicted by extrapolating the results of land subsidence for 2050. Consequently, for 2100 doubled land subsidence figure have been assumed.

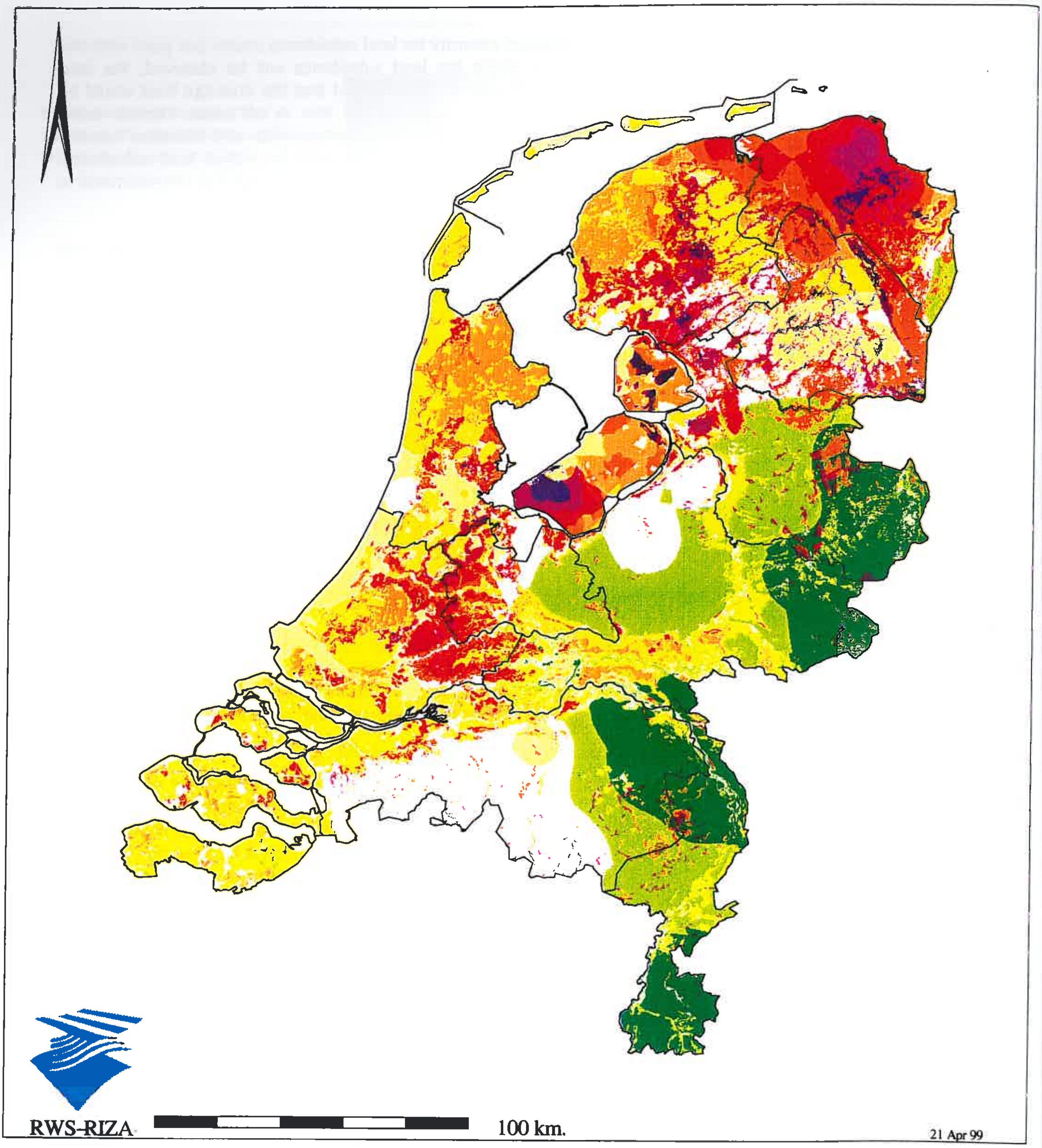


Figure 18. Expected land subsidence in 2050.

- subsidence more than 60 cm
- subsidence 40 –60 cm
- subsidence 30 –40 cm
- subsidence 20 –30 cm
- subsidence 10 –20 cm
- subsidence 5 –10 cm
- subsidence 2 –5 cm
- subsidence less than 2 cm
- no change
- rise less than 2 cm
- rise more than 2 cm

3.2 Climate Scenarios

General Circulation Models (GCM's) predict that global warming will result in higher temperatures and wetter conditions in Western Europe, especially during winter. Furthermore, a significant sea level rise is predicted. These processes may affect the groundwater system of the Netherlands significantly. The Intergovernmental Panel for Climate Change (IPCC, 1995) has given a lower-, central and upper estimate for the rise of temperature and the sea level (table 1).

The two climate scenarios, which have been analysed, are based on the IPCC IS92a greenhouse emission scenario. They are: (1) the impact of a temperature rise of 1*C and a sea level rise of 25 cm in 2050 (central estimate of IPCC for 2050) and (2) the impact of a temperature rise of 4*C and a sea level rise of 110 cm in 2100 (upper estimate of IPCC for 2100). The climate scenarios are respectively referred to as CEN2050 and UPP2100. They have been summarised in table 1. Because the uncertainties within climate changes the scenarios are presented as 'What-if'-scenarios. This section gives a description of the assumptions made to model the climate scenarios.

Table 5. Characteristics of the two climate scenarios.

Scenario	Temp. Rise	Sea level rise	Δ winter precipitation	Δ summer precipitation	Δ reference evaporation	Δ transpiration
CEN2050	+ 1 °C	+ 25 cm	6%	1%	4%	- 4 - - 12 %
UPP2100	+ 4 °C	+ 110 cm	25%	4%	15%	- 8 - - 25 %

3.2.1 Sea level rise

For the reference scenario 2050 and the climate scenarios, different changes in levels for the North Sea, IJsselmeer and rivers are assumed. Sea level rises in the North Sea for the reference scenario 2050 and the two climate scenarios were derived from IPCC (1995). The water level changes for the estuaries in the Southwest of the Netherlands are assumed equal to the level of the North Sea. The changes in level for the tidal part of the rivers Rhine and Meuse were estimated by interpolation between level changes in the North Sea and the remaining part of the rivers Rhine and Meuse. Changes in the IJsselmeer were derived from WL (1997). The final changes are presented in table 6.

Table 6. Change in sea level.

Scenario	Noordzee	Ijsselmeer	Markermeer	Randmeren	Noordzeekanaal	Rivers
REF2050	10	2	2	1	0	0
CEN2050	25	6	4	2	1	-8
UPP2100	110	63	30	26	3	-30

3.2.2 Change in evapotranspiration

Climate change will affect evapotranspiration. Doubling of atmospheric CO_2 level to 560 ppm may increase temperatures with 1.5 to 4.5 degrees. Open water evaporation will increase due to an increase in net radiation and temperature. On the other hand, the enrichment of the concentration of carbon dioxide in the atmosphere may alter the behaviour of plant species, like plant growth and stomatal resistance and consequently decrease the transpiration by plants. The change in transpiration influences the crop factor (section 4.4.2) used as input for MOZART. The crop factor also depends on the crop type, influenced by changes in land use, and the growing stage of a crop. These processes will change the actual evaporation. This section gives a description of the assumptions that were made about the crop factors and the reference evaporation in order to take this change in evapotranspiration into account.

The potential evapotranspiration is the evaporation that occurs when there are no limitations in water supply. At that moment, the soil moisture does not restrict plant growth. The open water evaporation is a fraction of the potential evaporation. It is also called the actual or reference evaporation. In the Penman formula, the reference evaporation is used in combination with the crop factor as a function for obtaining the potential evaporation (see equation 1).

Evapotranspiration can be defined as the loss of water from the soil by evaporation from the soil surface and by transpiration from growing plants and equals the sum of interception, evaporation of the soil and transpiration of the stomata and cuticle (equation 2). The crop factor used in MOZART accounts for transpiration, soil evaporation and interception. When adapting the crop factor for changes in transpiration, the relative contribution of transpiration in the crop factor for a certain growing stage has to be determined first. Relative contributions of transpiration, soil evaporation and interception for different crops and growing stages were obtained from results from the SWAP model (Van Dam *et al.*, 1996).

$$E_p = f\ E_o \qquad (1)$$

E_p = potential evapotranspiration
E_o = open water evaporation / reference evaporation
f = crop factor.

$$E_{max} = E_i + E_{sp} + E_{tp} \qquad (2)$$

E_{max} = potential evapotranspiration
E_i = interception
E_{sp} = potential soil surface evaporation
E_{tp} = potential transpiration

3.2.2.1 Change in reference evaporation

The increase of the reference evaporation was estimated by Brandsma (1995) using the Penman equation for a dataset containing the temperature and precipitation per month and the present relations between relative humidity, relative sunshine duration and the number of wet days. This gives a relation between temperature and reference evaporation for each month of the year.

The relation between temperature and reference evaporation was based on a significant correlation (0.05 level) between the relative humidity and relative sunshine duration on one hand and the number of wet days (precipitation amount> 0.3 mm) on the other hand. This correlation was used to obtain values for the relative humidity and relative sunshine duration for a range of daily precipitation amount (1970-1990) of De Bilt for each month. It has been assumed that these relationships remain the same in case of climate change. Together with monthly temperature series and monthly wind speed data, the calculated values were used to calculate the monthly open water evaporation with the Penman equation.

Brandsma assumed that in addition to the change in net radiation due to temperature change alone, the net radiation will increase with about 5 Wm^{-2} due to a doubling of the CO_2 concentration. This value corresponds with the predictions that are given in the IPCC-report (IPCC, 1990). In combination with changes in temperature of +2, 0 and -2 °C, different scenarios were considered. The change in reference evaporation due to an increase in temperature and net radiation is obtained by a comparison with the reference evaporation from the Bilt. The change in evaporation by an increase of 1 °C was derived by interpolation. A linear relationship for the change in evaporation by a change in temperature is assumed from the change of different calculations (+1, +2, and +3 °C). In combination with the total mean open water evaporation, the relative changes were calculated.

3.2.2.2 Change in transpiration

The extent to which plants are affected by a rising atmospheric CO_2 depends on the photosynthetic pathway. A distinction is made between plants possessing the so-called C_3 and C_4 photosynthetic pathway (Talz & Zeiger, 1991). The plants are called like this because of the intermediate compounds that have three four carbon atoms respectively. Most of the (agricultural) crops cultivated in the Netherlands belong to the C_3 group (Kimball *et al.*, 1993). Within MOZART, only corn has a C_4 photosynthetic pathway.

An enrichment of atmospheric carbon dioxide concentrations decreases the stomatal opening. This is due to the maintenance of a constant ratio between internal and external CO_2 concentration or because the stomata tend to keep the CO_2 level independent of external CO_2 level (Talz & Zeiger, 1991). The stomata of C_4 species are more sensitive to CO_2 enrichment than the C_3 species. A reduction of stomatal opening will affect the stomatal resistance. Because water vapour is lost by transpiration through the stomata, transpiration will be less when the stomatal opening will be less (the stomatal resistance will be higher). An increase of stomatal resistance will therefore decrease the transpiration per unit leaf area (e.g. Rozema, Wolf and van Diepen, 1991; Lawlor and Mitchell, 1991). However, an increase in leaf area, caused by a higher production, could minimise this effect (Rötter and van Diepen, 1994). Also the thickness of leaves may be affected. The thickness may increase, which may reduce the amounts of stomata per leaf area (Wolf, 1993) and decrease again the transpiration. A feedback mechanism by an increase of relative humidity and leaf surface temperature will minimise the decrease in transpiration. This will be less for forests because of the higher communication with the atmosphere.

The rising level of CO_2 stimulates the production of biomass in most C_3 species, while the effect on C_4 species will be small or absent (Rozema *et al.*, 1993). Kimball *et al.* (1993) found that the average increase in yield would be 33% for C_3 and 14% for C_4 species when a doubling of the atmospheric CO_2 concentration occurs. So an increase in efficiency of the photosynthesis will stimulate plant growth. The increase of the growth depends on whether the optimum temperature levels are reached or not. The number of stomata may not increase proportionally because the increase in biomass will mainly result in thicker leaves. The effect on the growth of plants will be less apparent under circumstances with severe nutrient deficiencies, which are necessary for growth (for example in nature reserves). On the other hand, growth may be reduced by enhanced UV-B radiation (Rozema, 1993). The enhanced UV-B results from the reduction of the stratospheric ozone layer.

Under the present day concentrations of CO_2, C_4 plants have a higher rate of photosynthesis. The growth and yield of C_4 plants is therefore greater than C_3 plants. At a CO_2 concentration of 700 *l/l (present concentration is approximately 350 *l/l) the rate of photosynthesis of C_3 species becomes greater than the rate of C_4 species. This leads to the expectation that the yield and growth of C_3 species will increase relatively more than C_4 species. Therefore, the competition between both species will change in more beneficial for C_3 plants, which could have effect on the composition of ecosystems and on the distribution of crops. C_4 -plants will suffer more damage from C_3 plants. At the same time C_3 plants will benefit more from a CO_2 rise than C4 more advantage over C_4 plants (Kimball *et al.*,1993). This may cause a shift of C_4 to C_3 plants, due to a change in competition (Kimball *et al.*, 1993; Arp *et al.*, 1993; Lenssen, 1996).

Hendrey *et al.* found that plants, which were enriched with CO_2, matured earlier and in general have greater agronomic yields. In spite of higher rates of photosynthesis and biomass accumulation, transpiration decreased. They also found no change in the evapotranspiration that was estimated from the residual of both the soil water balance and different energy balance methods between enriched and un-enriched plants. The reason was not clear. It was also found with three other methods. The experiment was done with cotton, a C_3 plant.

Table 7. Summary of the impacts of an increase of atmospheric CO_2 and UV-B radiation on vegetation and the influence of these impacts on the transpiration of plants. + indicates a positive effect. - indicates a negative effect en 0 indicates no effect.

Climate change, increase of	property of plant	C3	C4	Reference	transpiration C3	transpiration C4
	growth	+	0 / +	Rozema 1993; Kimball et al. 1993	+	+ / 0
CO2	maturation	-	-	Hendrey et al. 1993	-	-
	stomata density	-	-	Rozema 1995; Wolf 1993; Rotter & van Diepen 1994	-	-
-	feedback mechanisms (warmer leaves, higher relative humidity)				-	-
UV-B	growth	-	-	Rozema 1993	-	-
	tot. transpiration	-	-	eg. Rozema 1993; Wolf & van Diepen 1991; Lawlor & Mitchel 1991		

All these factors could influence the transpiration and consequently the potential evaporation. In table 5, the effects are summarised. Many of these effects are difficult and unpredictable to quantify. Therefore, it is difficult to include these effects in the simulation of the change in transpiration and evapotranspiration. Some will enhance and others will restrict the transpiration. Most of the literature references reviewed indicate a decrease in transpiration by an increase in the closure of the stomata. The change in transpiration as a result of a doubling of CO_2 has been measured for several crops (eg. Lenssen, 1996; Rozema, 1997; Spieksma *et al.*, 1996). To make an estimation of the change in crop factors by a change in transpiration the best option is to take a range of changes in transpiration from several plants of a crop type within MOZART. This is a time consuming process.

3.2.2.3 Sensitivity of hydrological models for changes in transpiration

The sensitivity of groundwater levels computed by MOZART for changes in crop factors and consequently changes in potential evapotranspiration has been determined with a test run from MOZART. Groundwater levels have been computed by MOZART for a period of 5 years for 6 plots identical in seepage flux, soil type and drainage relation, but with different crop types. The test run comprised the following crop types:

- grass,
- corn,
- other agricultural crops
- deciduous forest,
- coniferous forest,
- other nature area.

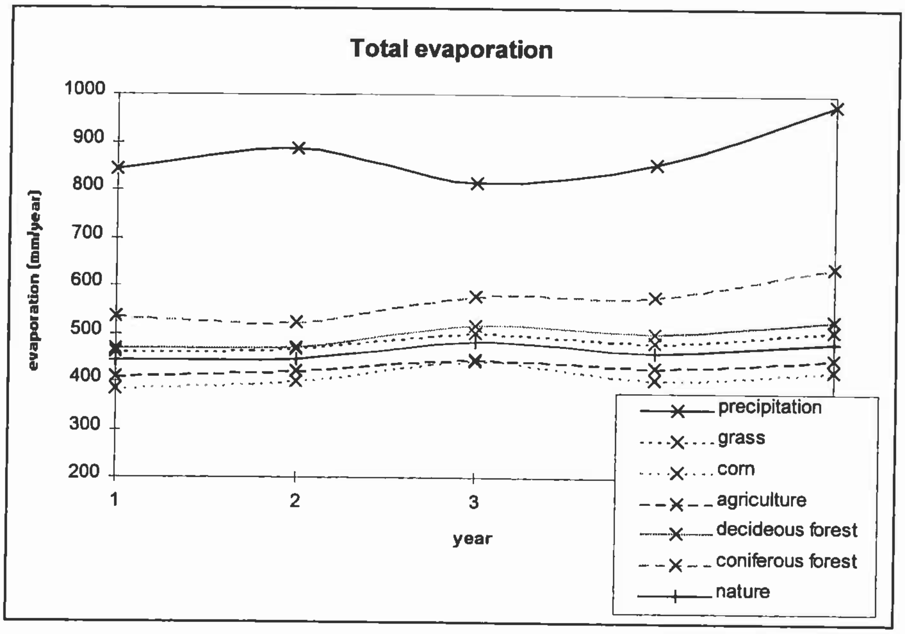
When for instance the sensitivity would be negligible, the assumption of the crop factor does not necessarily have to be accurate or could even be assumed to remain the same. Not changing the crop factor would be corresponding with Brandsma, who considers a prediction of change in crop factor to be too unsure.

The results of the simulation are presented in the figures of appendix 4. These figures should be interpreted in combination with the change of crop values over the year, presented in appendix 3 and table 6. The effect of the crop factor on the total evapotranspiration over the year seems quite significant. An increase of crop factors with approximately 150% results in an increase of evapotranspiration of 200 mm/year (figure 19). However, groundwater levels are relatively less affected by this change in crop factor.

Differences are mostly observed in autumn and spring, where the differences in crop factor are most apparent. The maximum difference experienced for the average groundwater level for a period of 6 months is between grass and other agriculture in early summer and amounts to about 30 cm. Furthermore a change in crop factor with for example 37,5%, derived by comparing values of grass and agriculture (first year, early summer, decade 10), will increase the groundwater level with approximately 30 cm. In the first ten day period of the fourth year of the model run a decrease of 12,5% causes a change of about 10 cm. Considering other decreases in crop factor by comparing the different crops at different decades gives an estimate of the change in groundwater level that may be computed. With a decrease of 1% of the crop factor, the groundwater level may increase with up to 2,5 cm.

In general, the effect of a change in crop factor on the groundwater level seems quite small. A small (few percentages) deviation of the predicted change in crop factor to the actual change in crop factor will not have a big influence on the groundwater level. When however the error becomes larger (37.5% or 12,5%), the effect on groundwater level is large, compared to the differences in groundwater levels that may occur when climate changes (see results). As stated in the previous section, the predictions for the change in crop are quite unsure. It is recommended to do more research on the change in total evaporation and especially on the change in transpiration.

Figure 19. Change in total evaporation by a change in crop factor, simulated by different crops.



3.2.2.4 Assumed decrease in transpiration

The decrease in transpiration, eventually assumed within the modelling approach, has been derived for the different land-use types using results from a crop simulation model, WOFOST (Rötter and van Diepen, 1994). This model describes the phenological development, growth and yield formation of a crop, based on genetic characteristics and environmental conditions with a calculation time step of one day (e.g. van Keulen and Wolf, 1986; van Diepen *et al.*, 1989). Major processes included are for example development, CO_2 assimilation, respiration and transpiration. The input data files of WOFOST contain information about:

- Meteorological data (e.g. daily minimum and maximum air temperature, global radiation, actual water vapour pressure,
- soil (e.g. transmission zone permeability in top- and subsoil, moisture availability, total pore volume) and
- crop characteristics (different crop parameters with information on physiological ageing of leaves, evapotranspiration, root depth, development rate).

Because the model accounts for the direct effects of CO_2 and its interactions with all climate variables like solar radiation, temperature, and rainfall, the model seems suitable for the assessment of the impact of changes in CO_2 concentrations on the transpiration rate of different crops.

Within the climate scenarios, simulated with WOFOST, the mean temperature has been increased with an average of 1.75 °C over the year. Precipitation was increased only in winter with 10% each day. In addition, water vapour pressure was adjusted to the increased temperature. Wind and global radiation were not altered. To include the effects of climate change on CO_2 assimilation, growth and water use efficiency, several crop characteristics have been changed to reflect the following changes according to Wolf (1993):

- CO_2 assimilation-light response curve of single leaves increase with increasing CO_2 concentration,
- maximum CO_2 assimilation is shifted to higher temperatures,
- increase of the thickness of leaves and
- a limited decrease in transpiration rate.

Rötter and Van Diepen (1994) found only slight changes in total evapotranspiration (crop value use) for future climate scenarios, whereas the crop production levels increase considerably. The difference between the predicted change in total evaporation (according to water limited production simulation) for the present situation and a future climate situation has been translated to a change in crop characteristics (crop factor), using the proportion of reference evaporation and potential evapotranspiration and equation 1.

The land use types 'nature', 'deciduous' and 'pine forest' have not been determined within WOFOST. For these land use types, the change of transpiration of 7% has been adjusted as a default value. The change in crop characteristics for the upper estimate 2100 was derived by extrapolating the changes assessed for 2050. The crop factors were only adjusted for the time of the year where the transpiration forms a considerable part of the total evaporation; mostly during the summer period. This decreases the difference in evapotranspiration between summer and winter. Table 8 presents the assumed changes in crop characteristics for the different climate scenarios. The changed and present distribution of the crop factor over the year is presented in appendix 3.

Table 8. Change in crop factor.

Crop	D crop factor 2050	D crop factor 2100	distribution over year	weighted mean
grass	-5%	-10%	0,7 - 0,8	0,75
corn	-15%	-30%	0,2 - 1,0	0,66
agriculture	-18%	-36%	0,2 - 0.9	0,7
deciduous forest	-13%	-26%	0,3 - 3	1,1
coniferous forest	-13%	-26%	0,6 - 6,8	1,7
nature	-13%	-26%	0,6 - 0,8	0,72

3.2.3 Changes in precipitation

Another input parameter of MOZART which will change as a result of climate change is the precipitation. Using the present relation between temperature and precipitation, the predicted temperature rise was translated to an increase in precipitation (Können *et al.*, 1997). Within the climate scenario 2050 the values have been increased with an average of 3% over the year, 1 % for the summer and 6 % for the remaining time of the year. Within the climate scenario 2100 these values are 12%, 4% and 25% respectively. These averages are based on predictions from KNMI (appendix). Furthermore the precipitation was assumed to be sinusoid over the year. figure 20 shows the predicted changes in precipitation for the two climate scenarios.

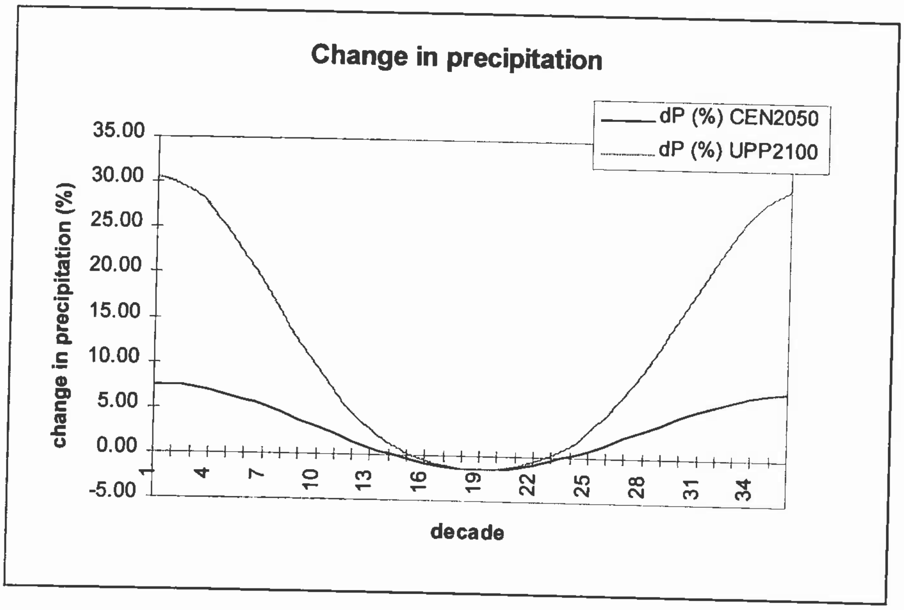


Figure 20. Change in precipitation for the climate scenarios.

4 Impact on the hydrological system

The model results are presented in terms of changes in the computed hydrological parameters between the present situation and the reference scenario 2050 and the two climate scenarios. The hydrological parameters, which have been considered, are:

- changes in mean spring groundwater levels,
- changes in upward and downward seepage fluxes,
- changes in discharges,
- changes in salt loads,
- changes in the relative amount of externally supplied surface water.

The model results are presented as the absolute changes between the reference scenario for the present situation (REF1995) and the scenarios for the future (REF2050, CEN2050, UPP2100). The change in hydrological parameters of the climate scenarios indicates the average impact of climate change. It should be taken into account that the effects may be different on a local scale. This difference may have a considerable impact on the effects for different functions such as agriculture, water management and nature. In appendix 5, a map of all provinces is presented to give a better description of the results.

4.1 Groundwater levels

MOZART computes the groundwater level per ten-day period. Within this study, the meteorological data of the years 1984 and 1985 are used for the calculation of the reference scenario. The groundwater levels per ten-day period are used to calculate the mean lowest groundwater level, also referred to as MLGL, and the mean highest groundwater level, referred to as MHGL. Both are derived by taking five most extreme values (highest or lowest). The MLGL is comparable with the groundwater level in summer and the MHGL will probably occur in winter. An empirical relation computes the mean spring groundwater levels (MSGL) from the MHGL and the MLGL. Roughly, the value for MSGL is determined for 80% by the MHGL and 20% by the MLGL. The changes in mean spring groundwater levels for the reference scenario (REF2050), central estimate 2050 (CEN2050) and upper estimate 2100 (UPP2100) are presented in figure 21, figure 22 and figure 23 respectively. Table 11 presents the computed changes in mean spring groundwater levels in terms of area distributions.

Autonomous developments

The autonomous developments, simulated within scenario REF2050, have a relatively small effect on the average groundwater level. For approximately 45 % the area, the mean spring groundwater level does not change, 18,2% of the area has a lowering of more than 5 cm and 18% has a rise of more than 5 cm. Changes occur especially in areas where the land subsidence is considerable. The increased gradient in the surface elevation causes more infiltration in infiltration areas and more upward seepage in seepage areas, which results in a lowering of groundwater levels in infiltration areas and higher groundwater levels in seepage areas. In these areas, the increase of upward seepage results in a rise of groundwater levels of approximately 10 to 25 cm. In the adjacent areas, the groundwater levels drop because of the increased surface elevation gradient caused by land subsidence.

Another cause of changes in computed groundwater levels in REF2050 are changes in land use between the present situation and the reference situation 2050. Changes in land use may result in a change of groundwater recharge and therefore in changes in groundwater levels. Changes in land use occur for example in the Veluwe area, the province of Friesland and the coastal dunes. Here 'forest' or 'grassland' has been replaced by 'other nature', which has a lower evapotranspiration. This results in a higher groundwater recharge and therefore in a rise of groundwater levels. The slight decrease in groundwater levels in the province of Zeeland may be the result of the replacement of agriculture (cereals and potatoes) by nature reserves, which generally causes more evaporation and less groundwater recharge. Effects of changes in groundwater recharge especially occur in areas with a low drainage density. In these areas, drainage resistances are high and a slight increase in groundwater recharge may lead to a considerable rise of groundwater levels and groundwater heads. Examples are the Veluwe area and some other areas in the south and eastern parts of the Netherlands.

Climate change

Climate change results in rises of groundwater levels over a much larger area. The effects increase with more climate change. Groundwater levels rise with 4 - 5 cm on average for a temperature rise of 1 °C (central estimate 2050) and 10 - 15 cm on average for a temperature rise of 4 °C (upper estimate 2100). However, the effects are variable. This is caused by the strong dependence of the rise in groundwater level on the drainage intensity. In areas with high drainage intensity, a larger proportion of the net precipitation will be discharged to surface water, rather than stored in the shallow groundwater system. On the other hand, in areas with a low drainage density, the extra precipitation will be stored in the shallow groundwater system rather than drained into the surface waters. Therefore, typical infiltration areas, such as Utrechtse Heuvelrug and the Veluwe area exhibit the highest increases in groundwater levels. The increase of the mean spring groundwater level in these areas is more than 1 meter with a maximum of 8 meter within scenario UPP2100.

In the areas with Holocene deposits, groundwater levels are determined by the surface water levels rather than by precipitation. Therefore, the impact of climate change on groundwater levels is smaller in these areas. All excess water can be drained and water demand can be replied via the drain system. Some of these areas show even a slight lowering of groundwater levels (especially in the upper estimate 2100). This may be the result of extremely high drainage densities of artificial drains and much lower drainage densities of canals and other main water courses. In that case, the precipitation increase during winter may result in only a slight rise of average highest groundwater levels and the drier conditions during summer may result in a considerable drop of average lowest groundwater levels. The net effect on mean spring groundwater levels may therefore become negative. In addition, the assumed steady state conditions within NAGROM may disturb the results to a certain extent.

The assumed doubled change in land subsidence for the upper estimate in 2100 results in a stronger rise of groundwater levels in the areas where land subsidence is large and a stronger decrease in adjacent areas in comparison to the central estimate for 2050. This is especially seen in province Flevoland, province Friesland and Groene Hart. Local effects of land subsidence are expected to be greater. The rise of the groundwater levels near the shore of the northern provinces and the delta areas is probably the result of the sea level rise.

Table 9. Distribution of changes in mean spring groundwater level (%).

Scenario	< -5 cm	-5 - 0 cm	no change	0 - +5 cm	+5 - + 10 cm	+10 - +25 cm	> +25 cm
REF2050	18.2	11.7	44.6	7.6	4.2	6.1	7.6
CEN2050	5.3	5.8	30.7	31.2	13.5	7.4	6.1
UPP2100	5.2	4.4	21.7	18.4	16.5	22.5	11

From earlier analyses on the effect of climate change on groundwater level, it was concluded that the effect of sea level change can only be determined within the direct area of the North seashore, the lake IJsselmeer and the tidal river area (working group climate change and land subsidence, 1997).

Climate change also results in a larger difference between the mean highest groundwater level (MHGL) and mean lowest groundwater level (MLGL). For example in Drenthe, the MLGL becomes 10 to 25 cm deeper and the MHGL becomes 10 to 25 cm higher. As in most cases, the drop of MLGL is almost equal to the rise of MHGL; the MSGL will generally rise. In some areas (for instance some parts in Friesland), the drop of MLGL exceeds the rise of MHGL by far. As already mentioned, this is possible in case of high drainage intensities of artificial drains and much lower drainage densities of canals and other main water courses.

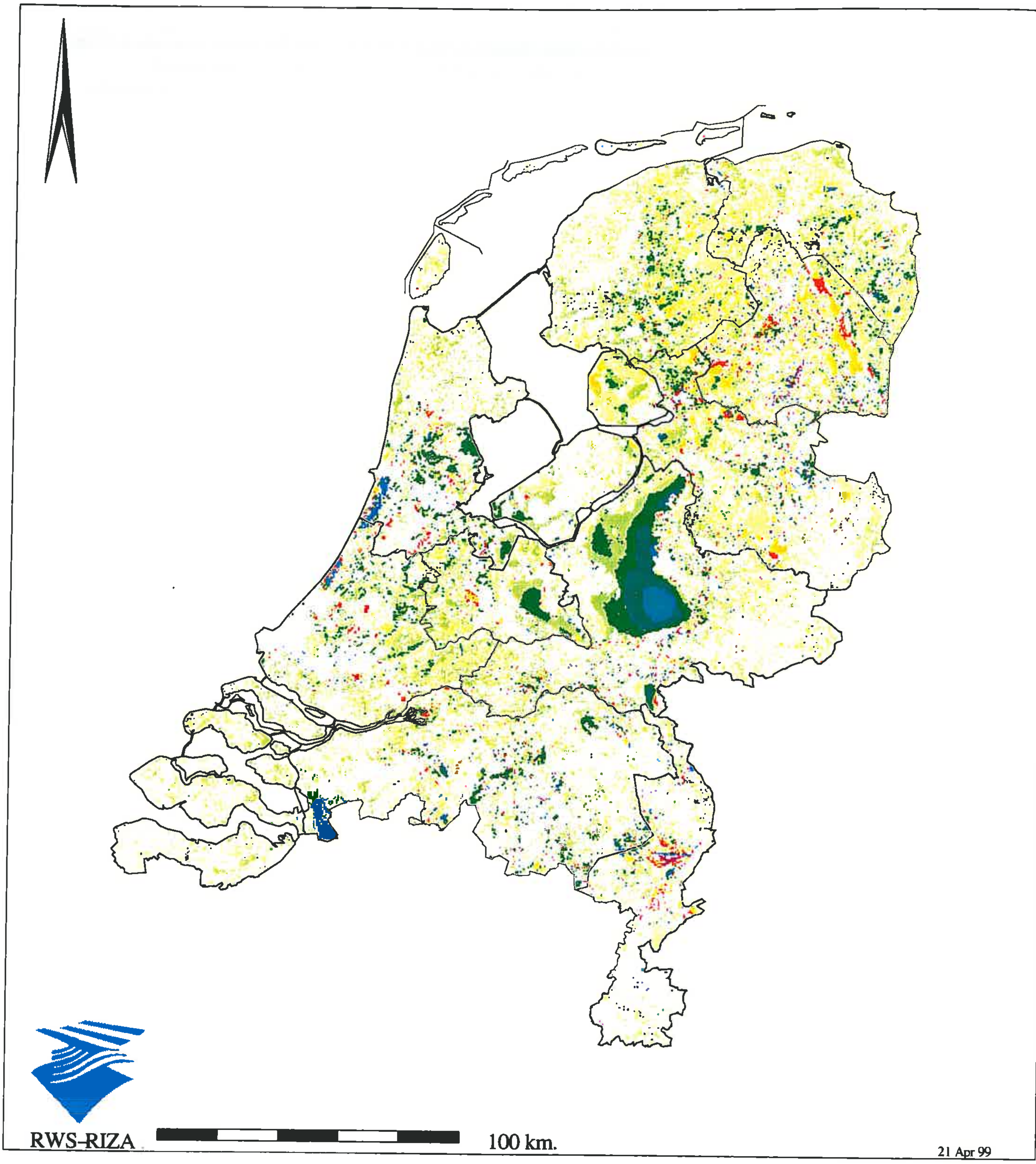


Figure 21. Change in mean spring groundwater level for the reference scenario (REF2050).

- decrease more than 1 m
- decrease 0.5 – 1.0 m
- decrease 0.25 – 0.50 m
- decrease 0.10 – 0.25 m
- decrease 0.00 – 0.10 m
- no change
- increase 0.00 – 0.10 m
- increase 0.10 – 0.25 m
- increase 0.25 – 0.50 m
- increase 0.50 – 1.00 m
- increase more than 1 m

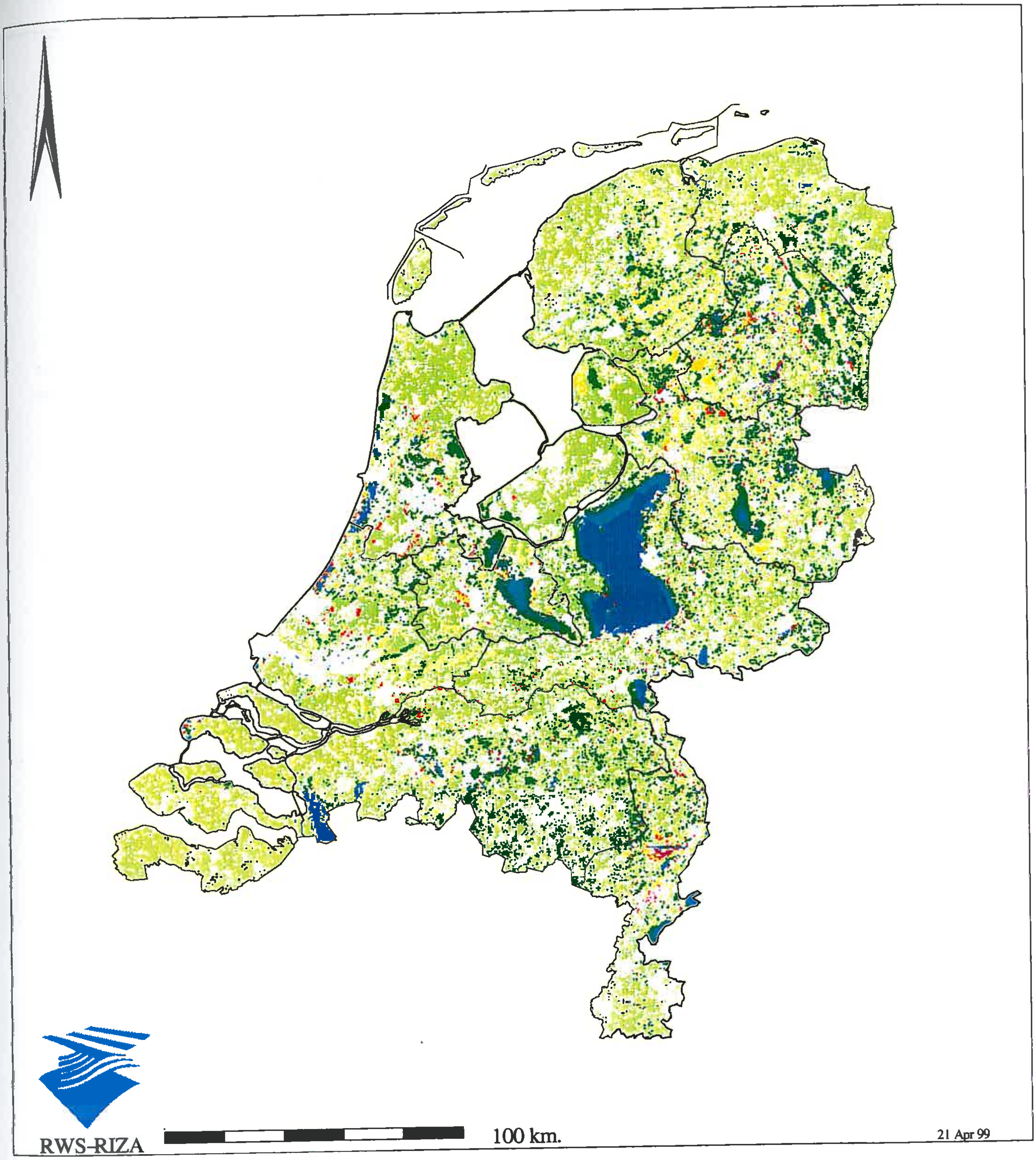


Figure 22. Change in mean spring groundwater level for the central estimate 2050 (CEN2050).

- decrease more than 1 m
- decrease 0.5 –1.0 m
- decrease 0.25 –0.50 m
- decrease 0.10 –0.25 m
- decrease 0.00 –0.10 m
- no change
- increase 0.00 –0.10 m
- increase 0.10 –0.25 m
- increase 0.25 –0.50 m
- increase 0.50 –1.00 m
- increase more than 1 m

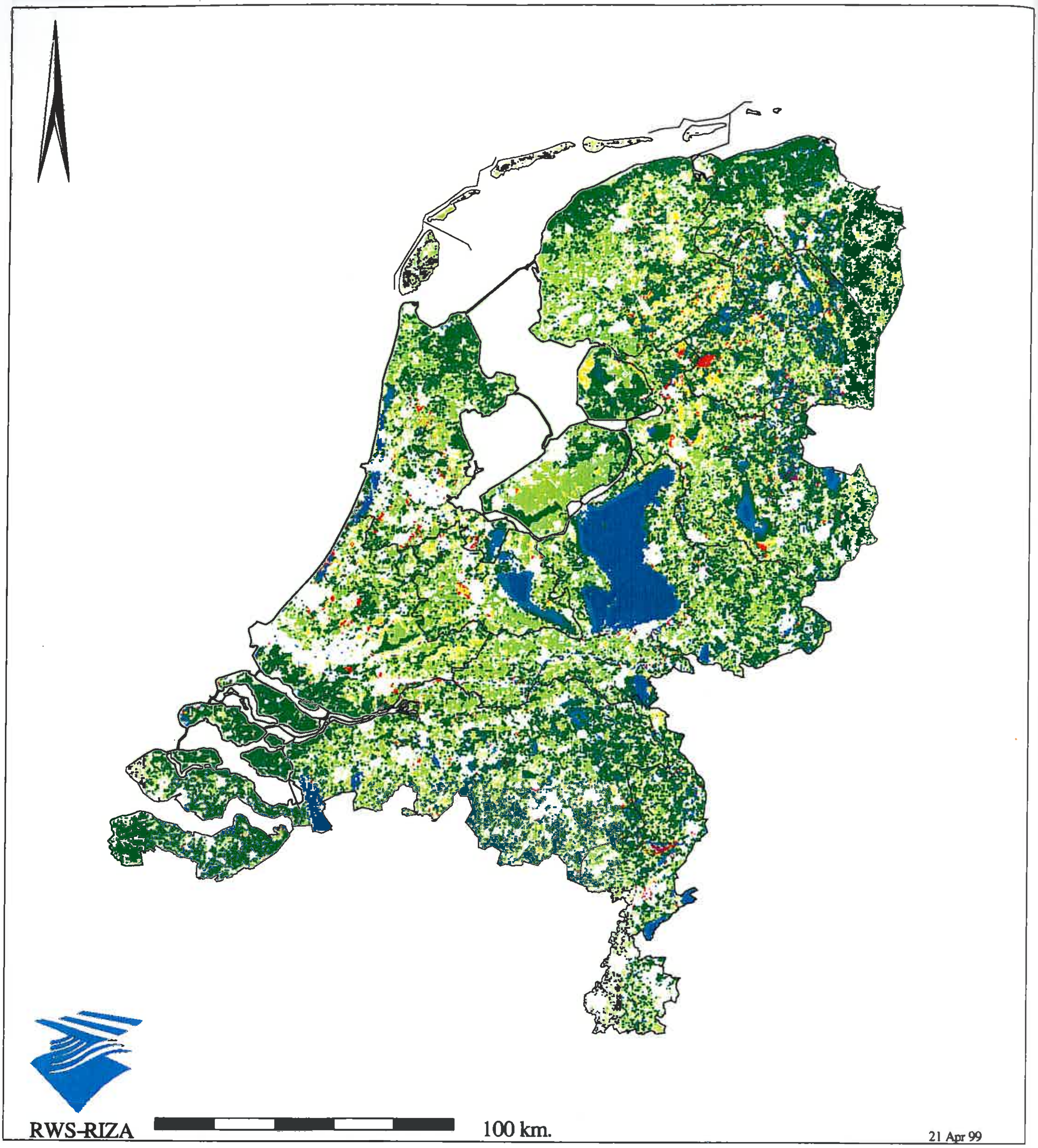


Figure 23. Change in mean spring groundwater level for upper estimate 2100 (UPP2100).

- decrease more than 1 m
- decrease 0.5 –1.0 m
- decrease 0.25 –0.50 m
- decrease 0.10 –0.25 m
- decrease 0.00 –0.10 m
- no change
- increase 0.00 –0.10 m
- increase 0.10 –0.25 m
- increase 0.25 –0.50 m
- increase 0.50 –1.00 m
- increase more than 1 m

4.2 Upward and downward seepage

Figure 24, figure 25 and figure 26 present the absolute changes in upward and downward seepage fluxes for the different scenarios in comparison with the present situation (REF1995). Table 6 explains the meaning of the values. A negative value of the change in seepage flux in areas with a net infiltration per day indicates an increase of infiltration fluxes. In areas where there is a net upward seepage flux condition, a negative value refers to a decrease in upward seepage.

Table 10. Declaration values of changes in upward seepage.

	Value figures 24, 25, 26	Change
Seepage areas	-	<
	+	>
Infiltration areas	-	>
	+	<

Autonomous developments

Within the reference scenario for the year 2050 upward seepage fluxes increase and infiltration fluxes decrease in the Holocene area (western). In the Pleistocene areas the opposite occurs. This is caused by the increased elevation gradients at the borderlines between Holocene and Pleistocene areas, as a result of land subsidence.

In the areas with reclaimed lakes the elevation gradient between the reclaimed lake itself and the surrounding areas decreases, because the peat area adjacent to the reclaimed lake is subjected to more land subsidence than the thin clay layer in the reclaimed lake itself. The reduced gradient results in a decrease of upward seepage in seepage areas (the reclaimed lake area) and a decrease of the infiltration in the adjacent peat areas. Moreover in Friesland the peat in brook valleys has more land subsidence than the surrounding area, which causes a higher elevation gradient and consequently more upward seepage in seepage areas and more infiltration in infiltration areas. An example of the increased elevation gradient at the borderline with Holocene and Pleistocene areas is the Vechtplassengebied. This is a peat area with upward seepage adjacent to a lateral moraine with infiltration.

Around the tidal parts of the river Rhine and Meuse the change in land use from grass to 'other nature' causes a reduction of the evapotranspiration. This results in an increase of upward seepage. Changes in land use also show effect in the dune areas, where it is assumed that coniferous forest will be replaced by nature in the future. Consequently, the evapotranspiration decreases, which causes an increase in downward seepage fluxes.

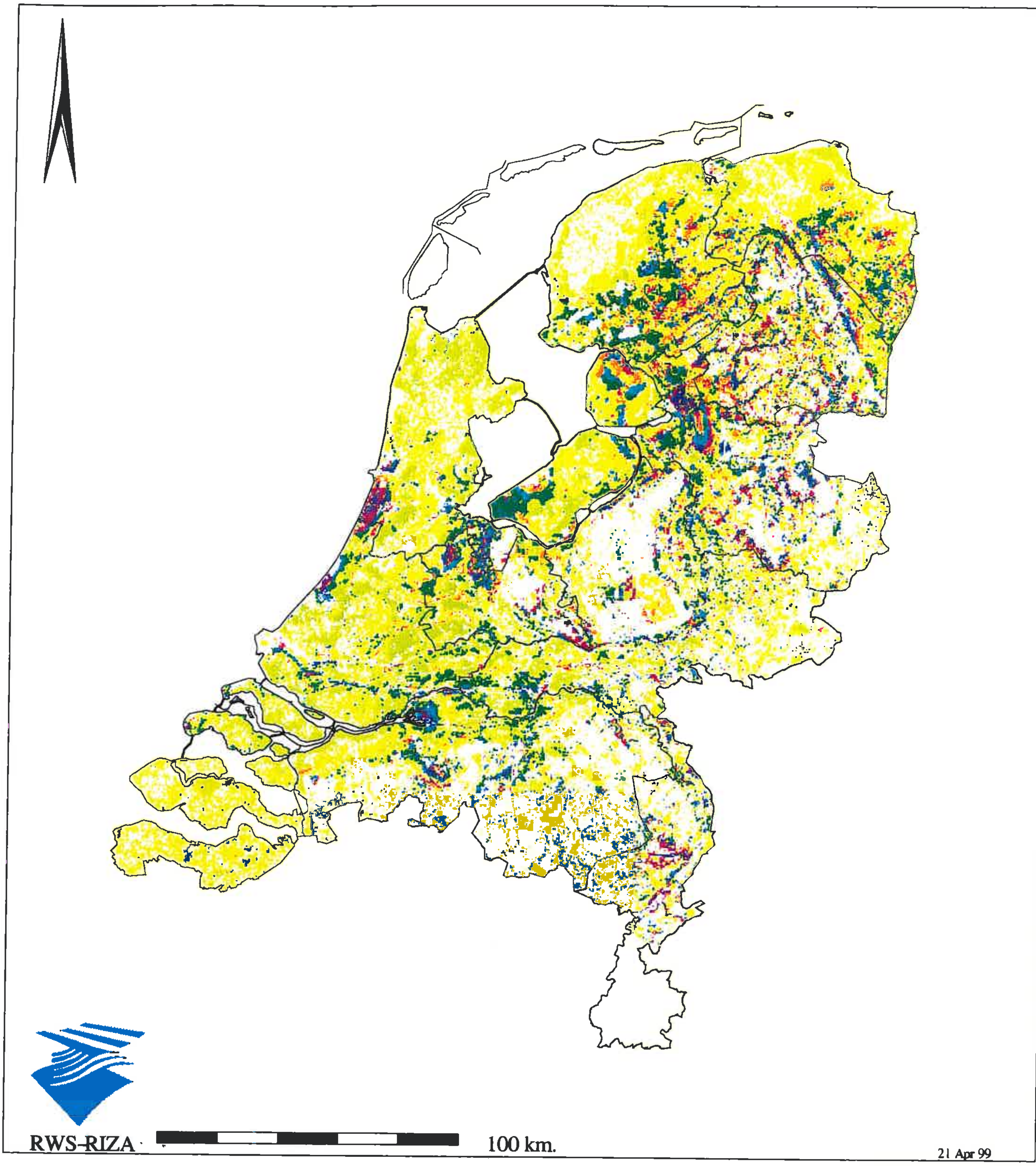


Figure 24. Changes in upward and downward seepage fluxes for the reference scenario 2050 (REF2050).

- decrease more than 0.50 mm/day
- decrease 0.25 –0.50 mm/day
- decrease 0.10 –0.25 mm/day
- decrease 0.00 –0.10 mm/day
- no change
- increase 0.00 –0.10 mm/day
- increase 0.10 –0.25 mm/day
- increase 0.25 –0.50 mm/day
- increase more than 0.50 mm/day

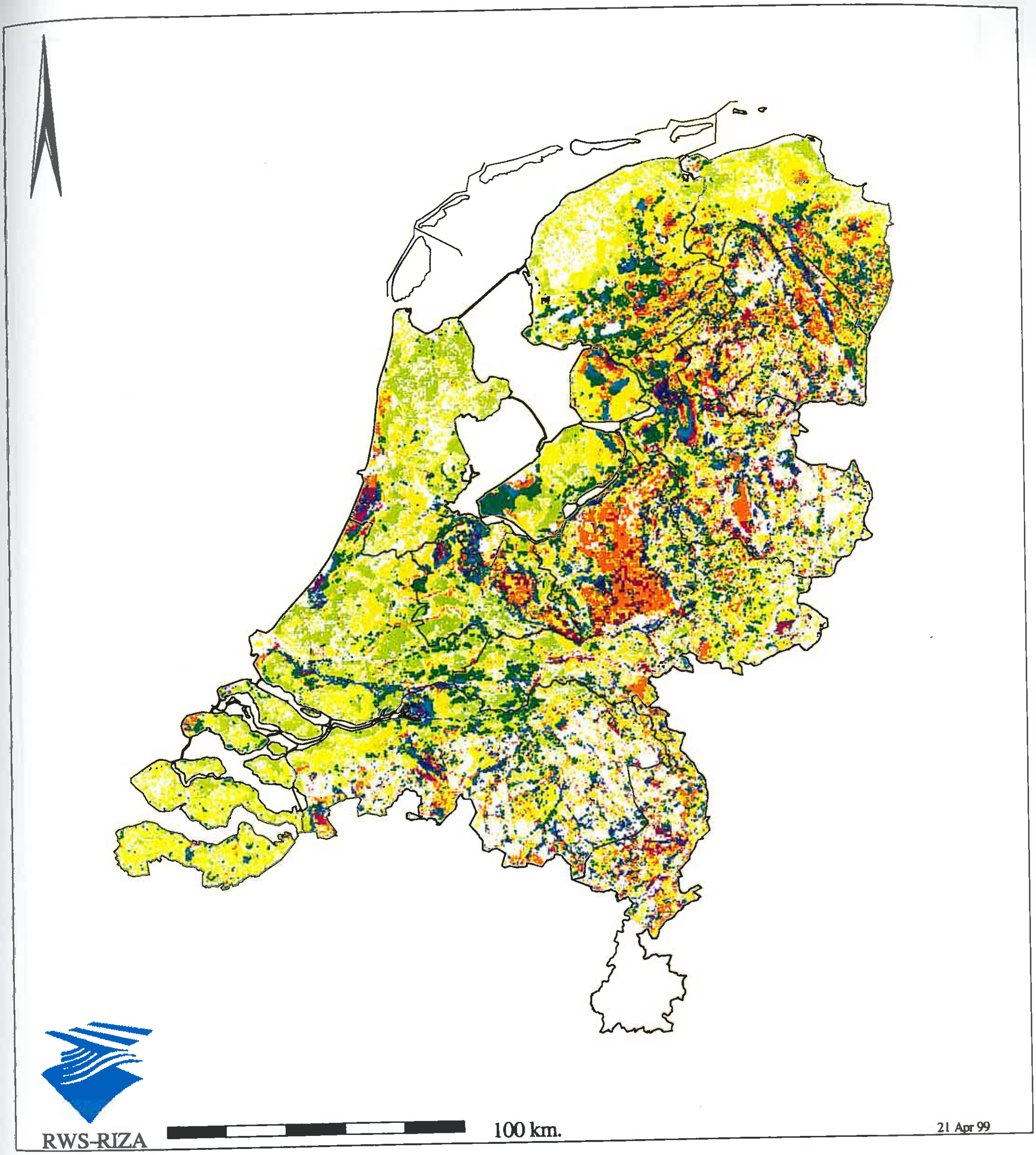


Figure 25. Changes in upward and downward seepage fluxes for the central estimate 2050 (CEN2050).

- decrease more than 0.50 mm/day
- decrease 0.25 –0.50 mm/day
- decrease 0.10 –0.25 mm/day
- decrease 0.00 –0.10 mm/day
- no change
- increase 0.00 –0.10 mm/day
- increase 0.10 –0.25 mm/day
- increase 0.25 –0.50 mm/day
- increase more than 0.50 mm/day

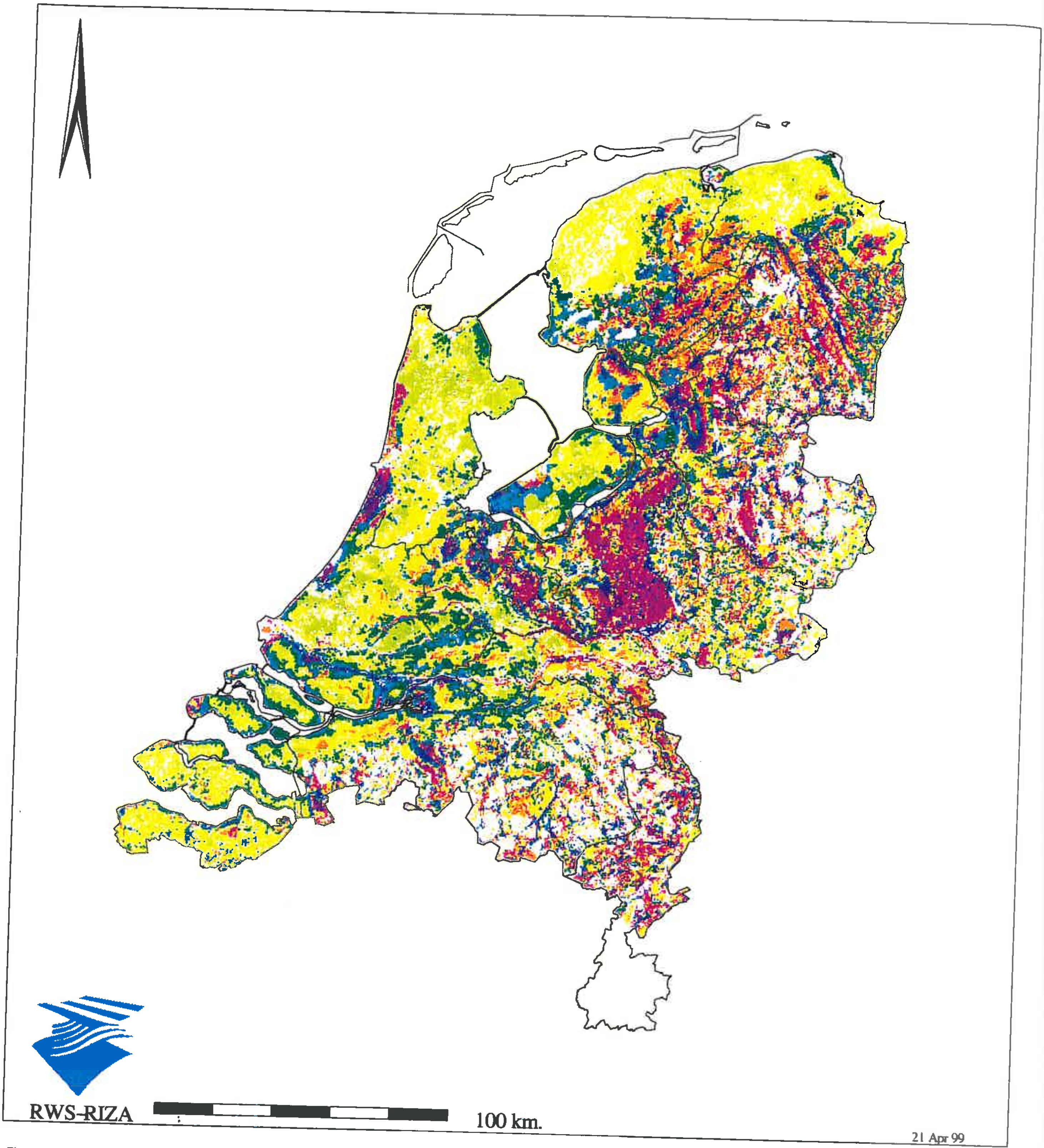


Figure 26. Changes in upward and downward seepage fluxes for the upper estimate 2100 (UPP2100).

- decrease more than 0.50 mm/day
- decrease 0.25 –0.50 mm/day
- decrease 0.10 –0.25 mm/day
- decrease 0.00 –0.10 mm/day
- no change
- increase 0.00 –0.10 mm/day
- increase 0.10 –0.25 mm/day
- increase 0.25 –0.50 mm/day
- increase more than 0.50 mm/day

Climate change

For the climate scenarios, the increased net precipitation results in more infiltration in infiltration areas and more upward seepage in seepage areas. The upper estimate for 2100 shows again more infiltration and more upward seepage over larger area. The assumed doubled land subsidence and the large increase of precipitation within the upper estimate of 2100 cause more differences between Holocene and Pleistocene areas, due to the higher elevation gradient and the fact that the drainage is more determined by gravity in the Pleistocene area than in the Holocene area. Especially in this scenario where the effect of a rise in sea level and IJsselmeer results in more upward seepage around the shore-lines. Within UPP2100, the rise in sea level is much greater than within the central estimate for 2050. The lowering of the water level in the Rhine shows a decrease in upward seepage over a large area.

4.3 Salt loads in surface water

The salt load into surface water is defined as the mean chloride load originating from the deep groundwater into a local surface water unit in kg per ha per year. A local surface water unit is a drainage unit. Within this unit, the concentration is assumed to be the constant, because surface waters are connected to each other. Multiplying the upward seepage fluxes with the average chloride concentration of shallow groundwater derives the salt loads. A salt load of approximately 1000 - 2000 kg per ha per year leads to an average chloride concentration within a range of 100 - 800 mg / l in the surface water (working group climate change and land subsidence, 1997). The value depends on the amount of upward seepage.

Autonomous developments

The distribution of changes in salt loads is presented in figure 27 and table 11. In the reference situation, for 1995 (assumed to be the present situation) the highest loads occur in Zeeland, Noord-Holland, Friesland and Groningen. General pattern is the increase of salt loads with climate change. The reference scenario 2050 learns that the change in salt loads is mainly caused by the land subsidence. This scenario shows a significant increase in salt loads. An exception is the dune area in Holland. In these areas, the change in land use causes an increase in infiltration and therefore a reduction of salt loads.

Climate change

Within the climate scenario for 2050, only slight changes can be observed (table 11). The upper estimate for 2100 shows more changes, but these may be caused by the assumed doubled soil subsidence. Probably the sea level rise results in an increase of the salt loads in the province Zeeland.

Table 11. Distribution of changes in salt loads (kg/ha/year) from groundwater as percentage area of total area.

Scenario	< -500	-400	-100	no change	0 - + 100	-400	> + 500
REF2050	0.5	1.3	9.2	56.1	26.2	5.0	1.7
CEN2050	0.4	1.3	7.4	56.1	27.1	5.4	2.3
UPP2100	0.4	1.3	4.7	55.8	27.2	5.5	5.0

4.4 Discharge

The discharges per ten-day period are summed for a year. The discharges presented in this study can be described as the water discharged from storage canals and catchment areas to the main canals. In figure 28 the difference between the scenarios and the present situation is presented as the percentage of the present amount of discharge of one district.

In the present situation, the discharges are the highest in the province Friesland, Flevoland and Holland. Figure 19 presents the relative change in the discharge within the different scenarios relative to the present discharge. The computed changes in annual discharges from different catchments are presented in table 11.

Autonomous developments

The autonomous developments result in a variable change of discharge, varying from a decrease with more than 5 % to an increase with 20 %. Approximately 86 % of the Netherlands has a change (increase or decrease of within a range of 0 - 5 %. In the Vechtplassengebied the discharge increase with 10 to 20 %, due to the large land subsidence. In Friesland the change in land use minimises the effect of the change in land subsidence on discharge. A large area of 'grass' is replaced by 'other nature', which reduces the evapotranspiration and thereby enhances the discharge. Despite the large land subsidence, the average discharge in Flevoland shows no changes in the reference scenario. This is probably because a change in seepage in an urban area does not come to expression in the discharge, which is an artefact of the modelling. Within the modelling approach, the urban area gets its discharge only from changes in precipitation. Furthermore, some areas show a decrease in discharge due to the larger surface gradient, which causes more infiltration.

In some areas, the observed effects of the reference scenario for 2050 are almost entirely caused by changes in land use. In these areas no land subsidence occurs. For example in the middle of Brabant and on the Veluwe only slight changes in land subsidence occur but the discharge increases or decreases with approximately 5 - 10 %. A change in land use causes a change in evapotransipration. Due to the low drainage density, a small change in net precipitation causes a considerable change in groundwater level and discharge.

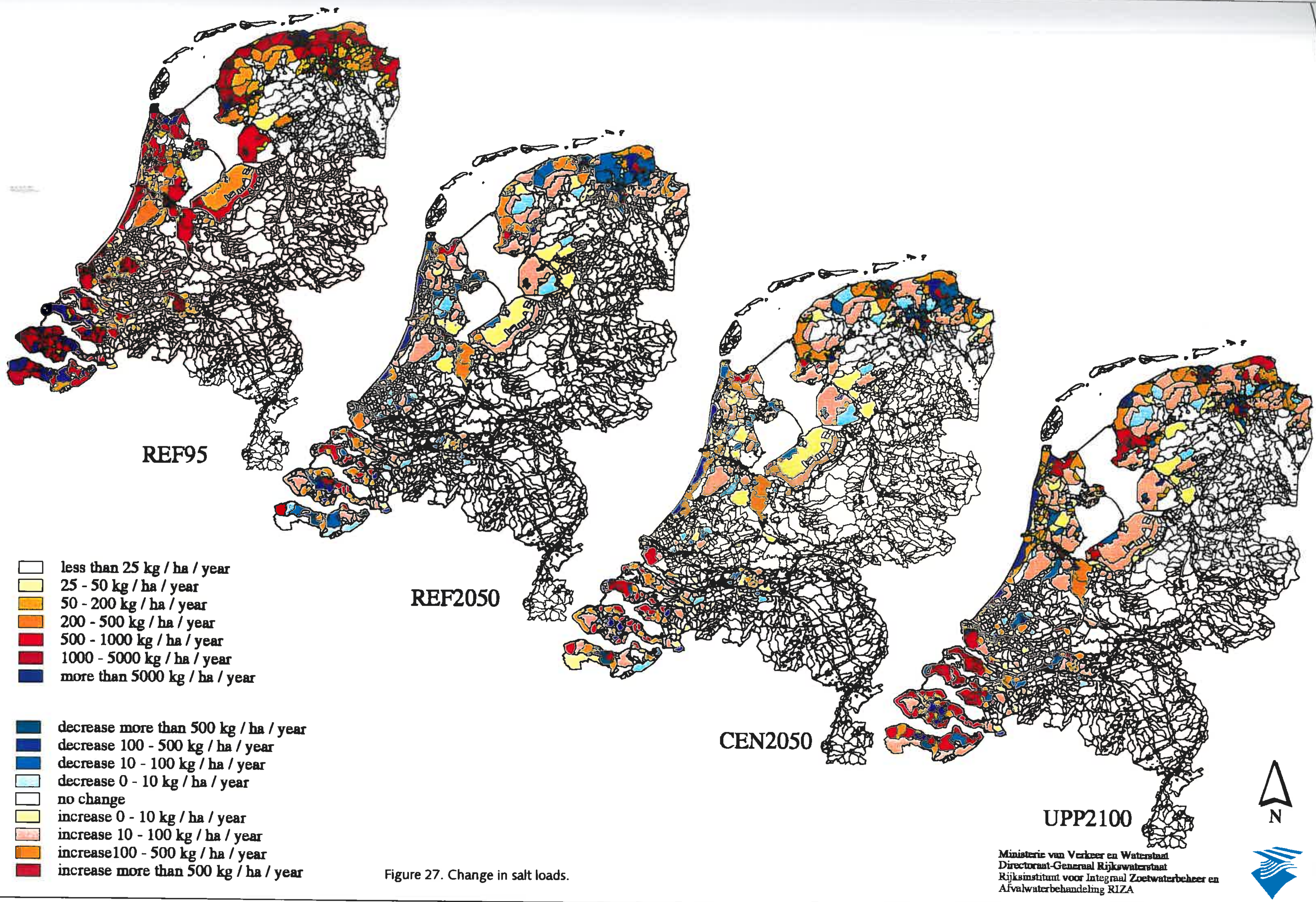
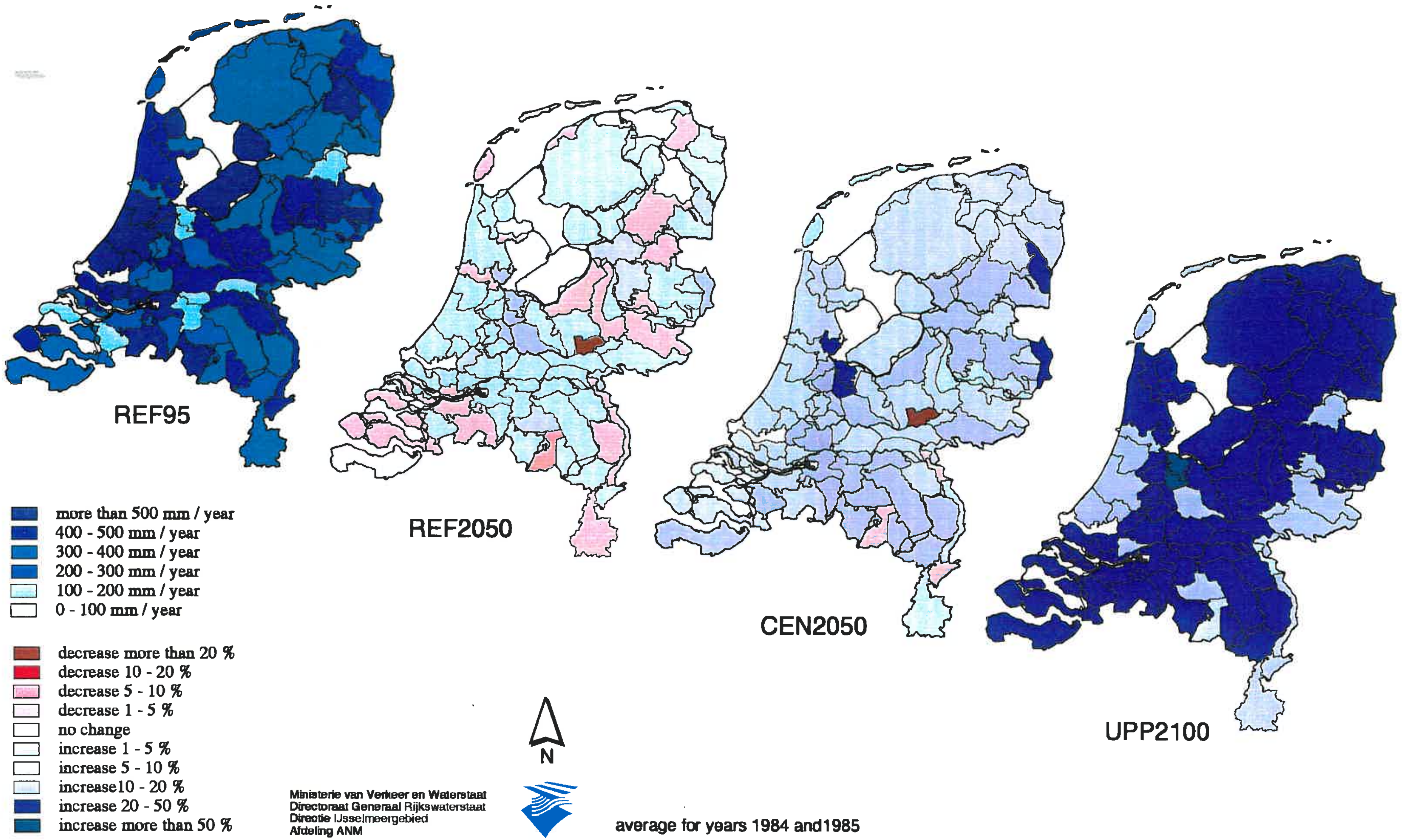


Figure 27. Change in salt loads.

Figure 28. Relative changes in annual discharge.



Climate change

Climate changes results in significantly more discharge in most areas. The relative large increase in discharge in the Vechtplassengebied within the reference scenario for 2050 is the result of the small discharge in the reference situation for 1995. A stronger climate change results in more increase of the discharge. For an increase in temperature of 1 °C, the discharge increases with approximately 12 %. Within the upper estimate for 2100, the increase of the average discharge is approximately equal to the increase in net precipitation in winter (25 %).

Table 12. Distribution of relative changes in annual discharges (%) as percentage area of the total area.

Scenario	< -5	-5-0	0 - +5	5-10	10-20	20-30	> +30
REF2050	3.5	21.8	64.4	8.8	0.6	0.8	0
CEN2050	0.5	0.4	1.9	57.2	38	1.2	0.8
UPP2100	0	0	0.9	0.3	19.8	62.1	17

4.5 Externally supplied water

The externally supplied water is defined as the water that is supplied from the rivers (Rhine and Meuse) in periods of drought. This will mainly be in the summer period. It is assumed that there is always enough water to supply. Consequently, the amount of water supplied is equal to the demand for water needed to supply all water users optimally from water. In further research, calculations will be made with the linked models MOZART and the Distribution Model (DM), which also accounts for the amount of water that can actually be supplied.

The results are presented as the difference between the relative amount of externally supplied water in the reference or climate scenarios and the present situation for every drainage unit (local surface water unit; figure 29). The relative amount of externally supplied water is the ratio of the amount of externally supplied water and the total amount of water available within a polder or catchment area. On a local scale, changes may be different. Especially in some areas where some catchment areas or polders occur.

Autonomous developments

In the present situation, the highest supply of externally water occurs within the provinces Noord-Holland and Zuid-Holland. The autonomous developments cause a slight decrease or increase of the externally supplied water. The increase occurs especially along the shore. This is probably caused by changes in land use, causing more evapotranspiration and therefore increases the demand for water in a district. The decrease occurs in areas strong land subsidence. In these areas, the upward seepage increases and the demand for externally supplied water decreases.

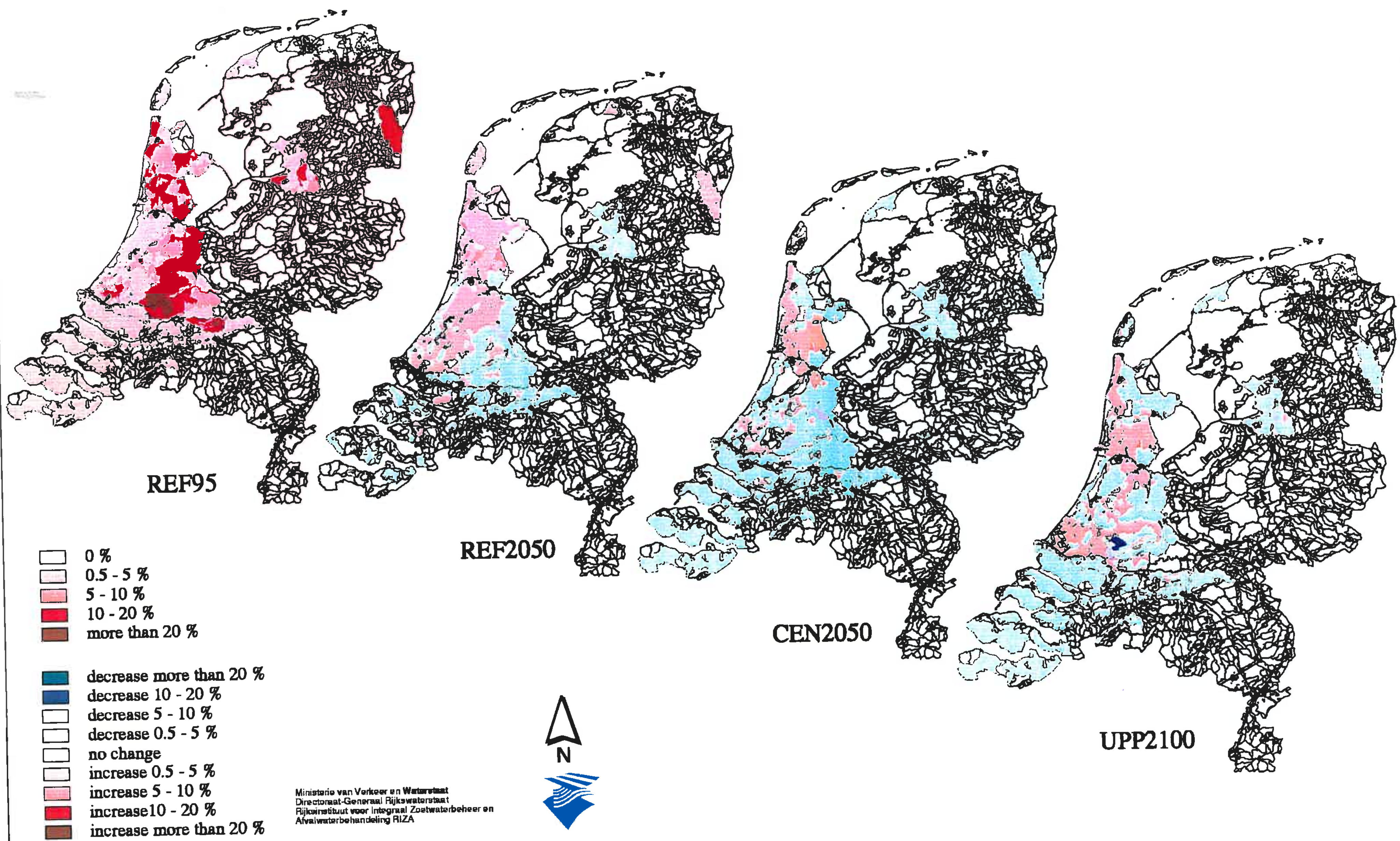
Climate change

Climate change causes only a minor change (increase or decrease) in the demand of externally supplied water. It is probably the rise of the sea level that causes a slight decrease in the relative amount of the supply of external water in the provinces Zeeland and Friesland. This is caused by the increase of upward seepage. An increase in salt loads will result in larger water demands for flushing. The flushing demand however is not computed by the models but imposed as a boundary condition to the models. They have not been adjusted for increases of salt loads. This may result in an underestimate of the supply of external water in Zeeland and Friesland.

Table 13. Distribution of annual relative amount of externally supplied water (%) as percentage area of total area.

Scenario	< -5 %	-5 - 0 %	no change	0 - +5 %	+ 5 - + 10 %
REF2050	0.2	9.7	75.2	14.7	0.0
CEN2050	0.4	20.8	71.6	7.2	0.0
UPP2100	0.5	19.8	70.4	9.3	0.0

Figure 29. Change in relative amount of externally supplied water.



4.6 Discussion

The greatest uncertainties in the assumptions made are included in estimations of changes in precipitation and evapotranspiration and especially in the changes of transpiration rates. For the computations, we assumed a considerable decrease of the transpiration of plants, due to the higher concentrations of atmospheric CO_2 (table 2). However, an increase in leaf area by an increase in temperature could minimise this effect (Rötter & van Diepen, 1994). Also, plant growth may increase in some cases, depending on whether the optimum temperature level of photosynthesis is reached or not, and on the availability of nutrients (eg. Kimball *et al.*, 1993; Rozema, 1993). Consequently, an increase in growth will have an increasing effect on transpiration rates. On the other hand, an increase of relative humidity and of the temperature of the leaf surfaces may again have a reducing effect on transpiration. Above all, it can be expected that within the agricultural practice, the increased CO_2 concentrations will result in the development of crop variants that yield extra production.

As can be seen in section 4.4 quite some information (most on site-scale) is available on the different processes and feedback-mechanisms resulting in a change of transpiration fluxes. In addition, crop growth models may give some quantification of changes in transpiration, provided that these models have been calibrated on site measurements. The net effect on transpiration is hard to quantify at the national scale.

To calculate the amount of externally supplied water it was assumed that the supply of water is not limited. Consequently, it is assumed that the demand for water is always supplied. Within this modelling approach, the amount of externally supplied is therefore equal to the demand for water. This could overestimate the groundwater levels in dry periods. The demand for water shows only slight changes. Therefore, it depends mainly on the present situation whether or not the demand for water can be supplied. Climate change results in a change of the discharges of the rivers Rhine and Meuse; higher discharges in the winter and lower discharges summer. Especially in summer, there may not be enough water to supply. These changes could not be taken into account within this modelling approach. In addition, in order to compute the effects of changing discharges of the river Rhine and to take the limitation of the externally supplied water into account (another symptom of global warming), NAGROM, MOZART and MONA will be linked to the surface water model, DM.

5 Impact on water system functions

Groundwater in the Netherlands has a number of socio-economic and ecological functions. Within this study, a distinction has been made between agriculture and nature. Climate change may influence the functions through changes in quantity and quality of groundwater. Both may influence nature and agriculture in that area. This section describes the impact of the calculated hydrological changes caused by climate changes on the functions of water. These effects have been quantified with an eco-hydrological and agro-hydrological model.

5.1 Nature

The ecological impacts of the autonomous developments and climate change scenarios have been quantified with the eco-hydrological model DEMNAT. The effects are related to the impacts on vegetation of the (semi)terrestrial ecosystems (e.g. wet/moisture heath land, peat areas and flowery meadowlands) and regional water systems (ditches and small lakes). With the conservation valuation module, the ecological changes are expressed in terms of changes in conservation values. This makes it possible to determine what the ecological changes mean for the nature in the Netherlands.

Table 14 gives a review of the net ecological effects in terms of the summed conservation values. These are the total changes of conservation values summed for all ecotopes in each gridcell. The results of DEMNAT allow comparisons between different scenarios but have no absolute value (Van Ek *et al.*, 1999). Therefore, the changes of the conservation values are also given as percentage of the conservation value of the present situation and as percentage of a reference for maximum restoration. The latter is based on the TRENDBREUK-scenario according to Kors *et al.* (1996).

Within the TRENDBREUK-scenario it is assumed that the problems and potentials of different functions are managed in a structural manner and as good as possible until the year 2045. In addition, the lowering of the dose effect functions on biotic restoration (return of vegetation by seed dispersion and germination from seed bank) are set to zero (first value, 43681 cvu). The TRENDBREUK-scenario is calculated with both the lowering factors, both the biotic and abiotic restoration (return of the original site factors) set to zero.

The maximum restoration is the percentage of the difference between the present total conservation values (36366 conservation value units) and the total maximal feasible conservation values from the TRENDBREUK-scenario (43681 to 45477 conservation value units) in the Netherlands. This percentage indicates to which amount the difference between the actual total conservation value and the maximal feasible conservation value with water management against desiccation (Watersysteemverkenningen, 1997). A percentage of 100% indicates that with water management against desiccation maximal feasible conservation value is realised. The maximal feasible conservation value is determined within the scope of the watersysteemverkenningen (1997) and is used in this study to indicate the magnitude of the calculated changes.

Table 14 indicates that autonomous developments have limited ecological effects compared to the climate change scenarios. A stronger climate change (scenario UPP2100) results in a larger increase of the total conservation values in the Netherlands. Figure 31, figure 32 and figure 33 show the spatial distribution of the gain of conservation values per square kilometre. They indicate both decreases and increases. Because the increases have the upper hand, the total changes in the conservation value are positive.

Table 14. Changes in nature conservation values in conservation value units (cvu), as percentage from the actual total conservation value in the Netherlands and as percentage from the maximum restoration.

Scenario	dN (cvu)	dN/N_{pres} (%)	$dN/N_{restoration}$ (%)
REF2050	454	1	5 à 6
CEN2050	1599	4	18 à 22
UPP2100	3787	10	42 à 52

dN change conservation value (Nscenario-Npres)
Npres present conservation value,
Nrestoration difference between the present conservation value and the maximum possible conservation value, based on the TRENDBREUK scenario.

Autonomous developments

The autonomous developments show a small increase of the total conservation values in the Netherlands. Figure 31 indicates that the spatial distribution of the conservation values differ largely over the area. In the peat areas of the Holocene part of the Netherlands DEMNAT has predicted a gain of conservation values. However in the same areas adjacent to the areas with land subsidence the upward seepage fluxes decrease. Consequently, the conservation values decrease. Despite the large changes of the mean spring groundwater level and upward seepage caused by the land subsidence in the province Friesland, there are no changes in conservation value calculated. This is because there is not enough information on the occurrence of plant species (FLORBASE) in this area. On the higher sandy ridges, especially in the brook valleys of the province of Drenthe and the dunes, the seepage fluxes and the groundwater levels decrease, which results in a decrease of the conservation values.

The total change of conservation value of the individual ecotopes is more or less related to the initial (actual) distribution of the ecotopes and the change of the groundwater level. Ecotopes, which occur in a larger area in the Netherlands, have a higher increase of the total conservation value in the Netherlands (figure 30). These ecotopes benefit in a larger area of the increase of the groundwater levels. Consequently, the more (moderately) nutrient-rich ecotopes contribute to a larger extent to the change of the total conservation values. The more (weakly) acid ecotopes show only a slight increase or even a decrease in conservation value, because they grow mainly in areas with a decrease of the MSGL. Therefore, ecotopes K21 and K41 (respectively wet and moisture heathland), situated in the province of Drenthe, decrease in conservation value. The influence of salt intrusion might be slightly noticeable in the increase of the better development of ecotope bA10 in the province of Noord-Holland. According to scenario REF2050 the (moderately) nutrient-rich ecotopes A17, A18, K28, K28 will be better developed in (mainly) the Groene Hart as a result of the autonomous developments.

Climate change

In general, climate change results in an increase of the groundwater levels, which causes an increase of the conservation values in almost all the areas with groundwater dependent ecosystems. The increase of the upward seepage in the lower Holocene part of the Netherlands results in a higher increase of the conservation values than in the reference scenario with the autonomous developments. Also in the higher Pleistocene part of the Netherlands the conservation values increase more. This is the result of the stronger increase of the groundwater levels in this part of the Netherlands. The climate scenarios not only indicate an increase of the conservation values but also an expansion of the occurrence of groundwater dependent ecosystems in the Netherlands.

On a regional scale the changes caused by climate change, may be different due to a local lowering of the upward seepage or groundwater level. The decrease in conservation values in the province of Drenthe as a result of the autonomous developments, disappears to a large extent in the climate scenarios. This is a result of the counteracting effect on hydrology when climate changes. The land subsidence over a larger period in the upper estimate for the year 2100, results in a larger difference of the groundwater levels and fluxes between the peat areas which subside compared to the adjacent areas. This causes an increase of the wet conservation values in the peat areas and a decrease of the wet conservation values in the adjacent areas. In some areas, the increases are large because both the groundwater level and the upward seepage increase.

Almost all ecotopes will be more developed when the temperature rises. Especially wet ecotopes K21, K22, K27, K28, H22, H27, H28 increase in conservation value. These are ecotopes, which grow mainly in the eastern Pleistocene part of the Netherlands, which have a larger increase of the mean spring groundwater levels. The ecotopes, which grow already on moisture sites, show only small changes.

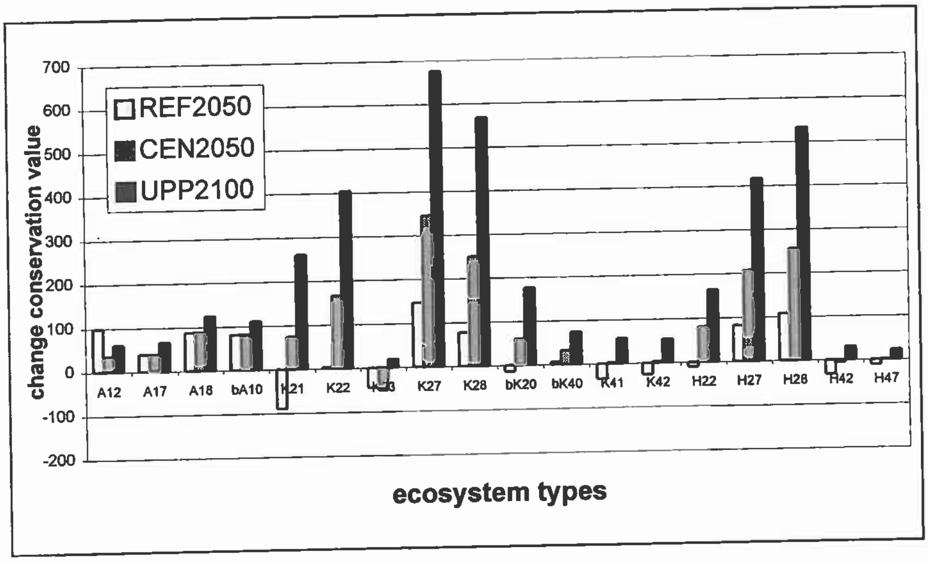


Figure 30. Change in total conservation value in the Netherlands for the individual ecotopes.

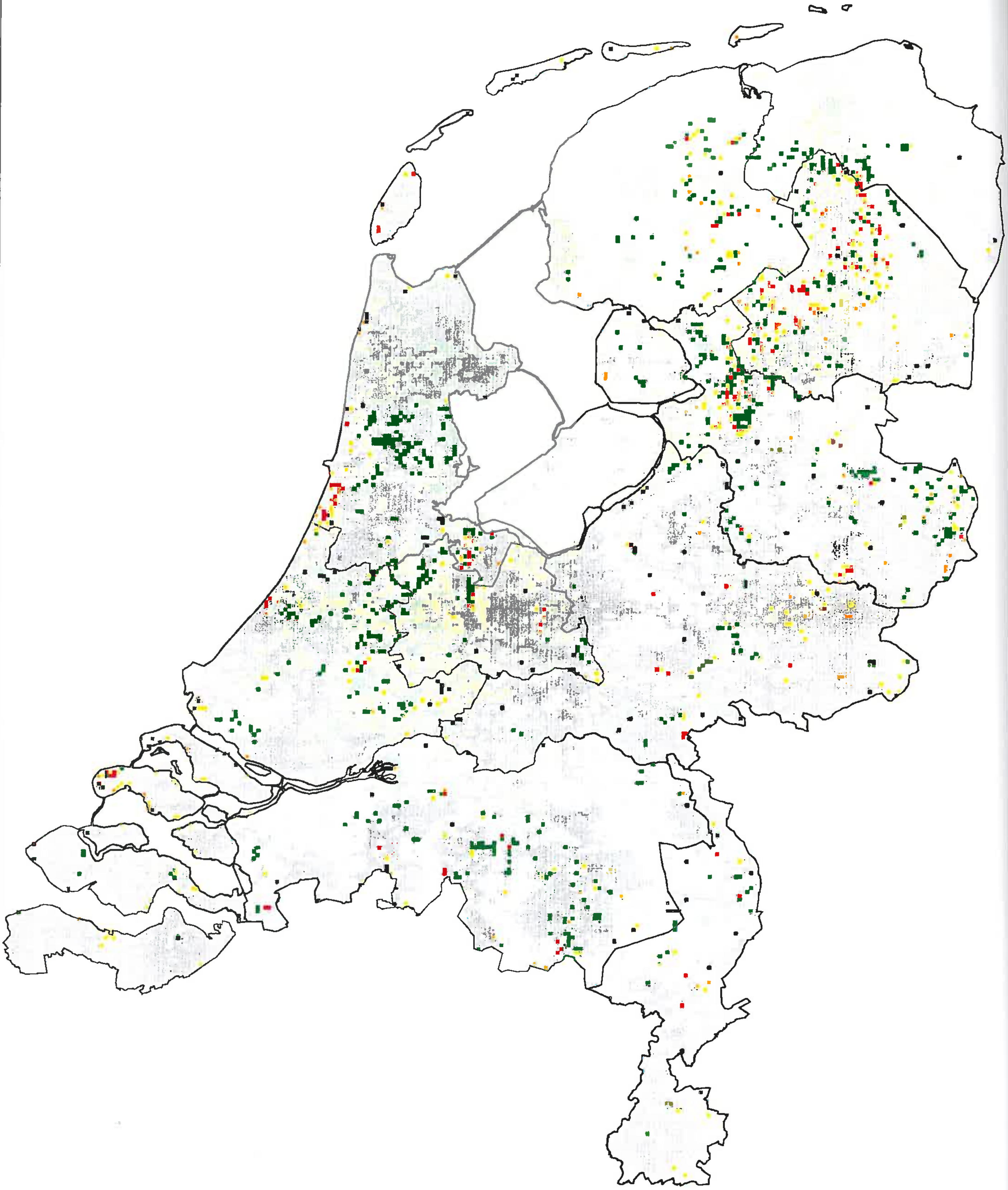


Figure 31. Change conservation values per square kilometre for the reference scenario 2050.

- less than -2
- -2 - -1
- -1 - -0.5
- -0.5 - -0.001
- -0.001 - 0.001
- 0.001 - 0.5
- 0.5 - 1
- 1 - 2
- more than 2

0 20 40 60 Kilometers

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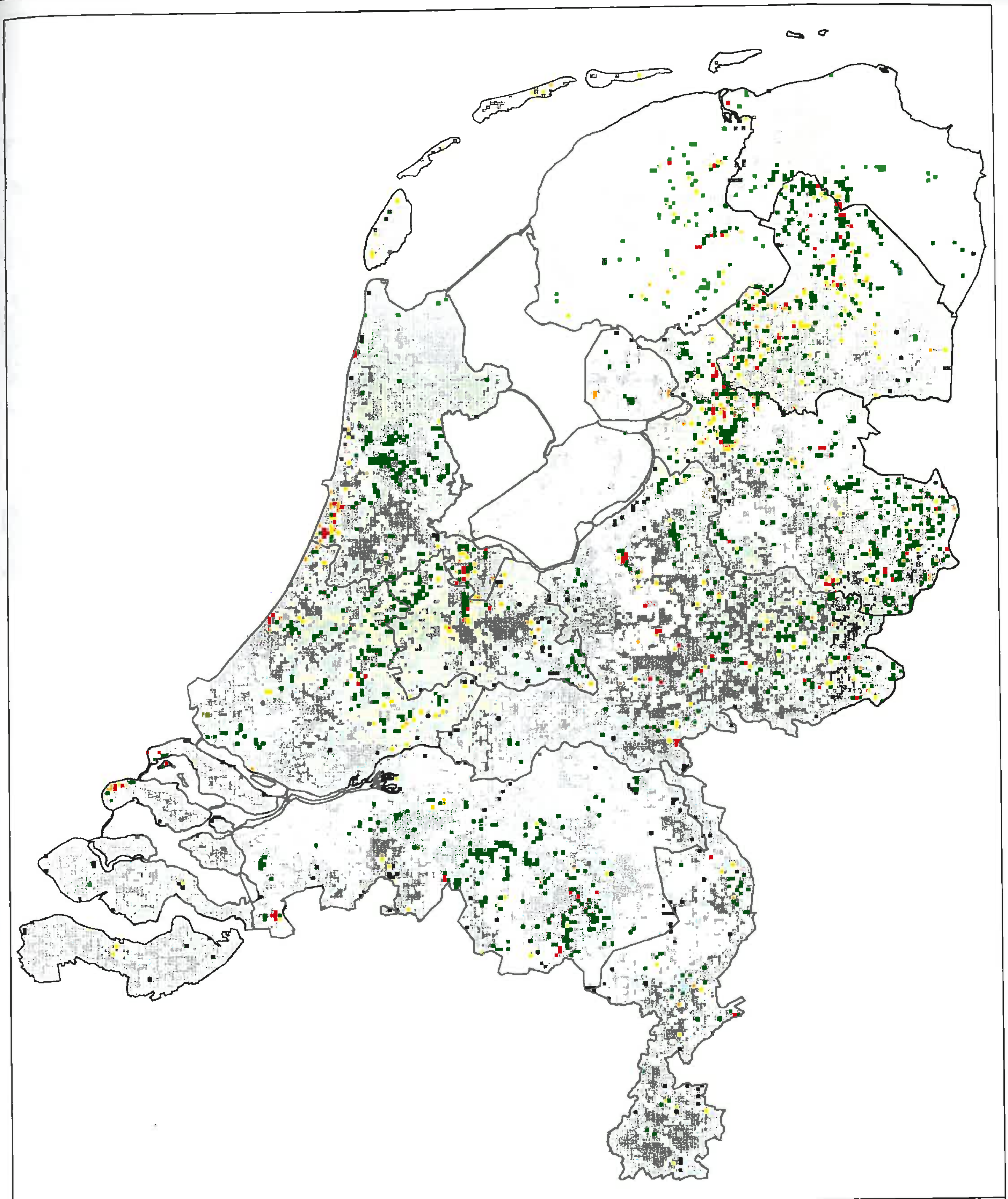

Figure 32. Change conservation values per square kilometre for the central estimate for the year 2050.

- less than -2
- -2 - -1
- -1 - -0.5
- -0.5 - -0.001
- -0.001 - 0.001
- 0.001 - 0.5
- 0.5 - 1
- 1 - 2
- more than 2

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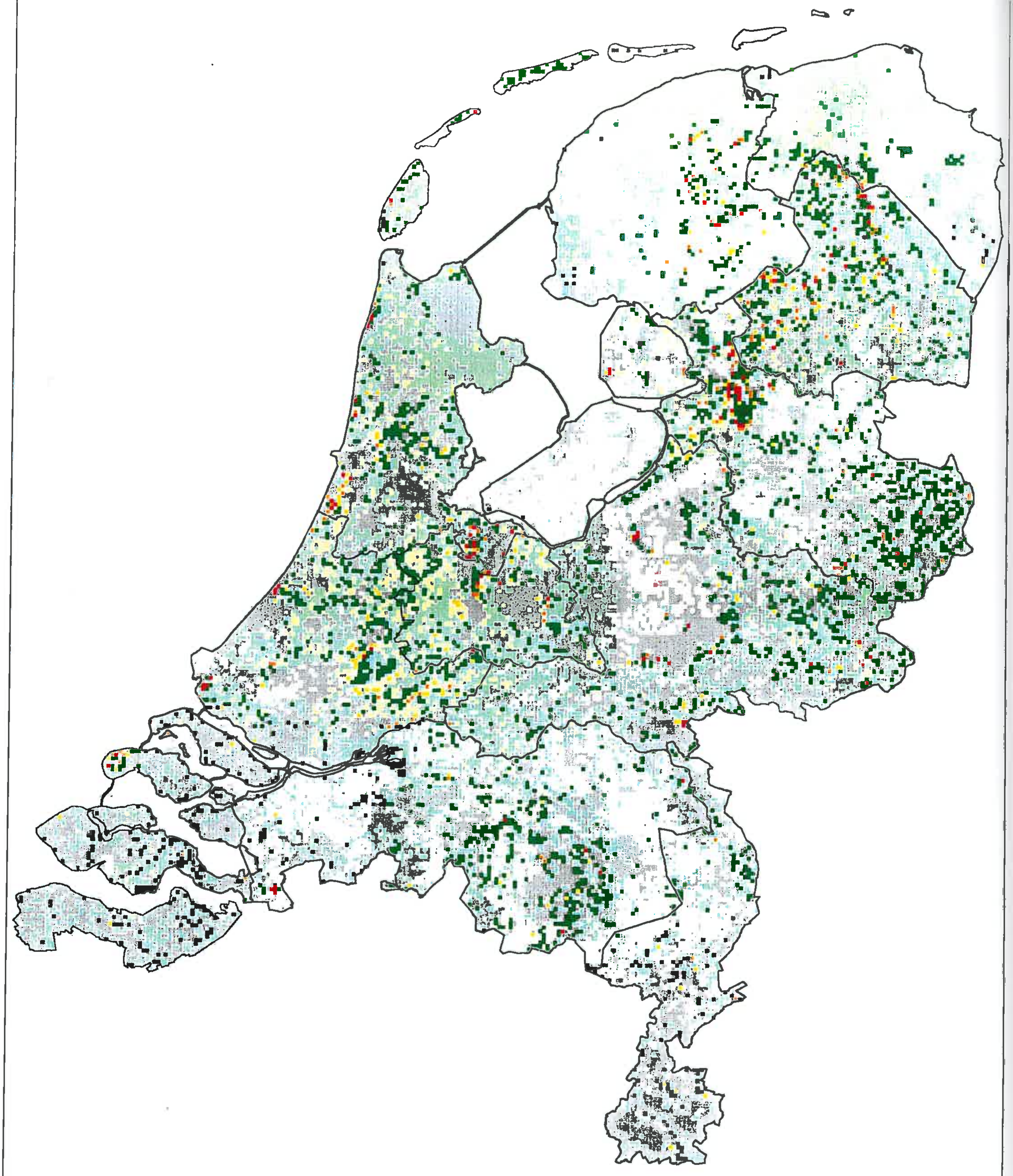

Figure 33. Change conservation values per square kilometre for the upper estimate for the year 2100.

- less than -2
- -2 - -1
- -1 - -0.5
- -0.5 - -0.001
- -0.001 - 0.001
- 0.001 - 0.5
- 0.5 - 1
- 1 - 2
- more than 2

0 20 40 60 Kilometers

N

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5.2 Agriculture

The impact of the calculated hydrological changes on agriculture has been quantified with the agro-hydrological model AGRICOM. The AGRICOM calculations result in an amount of damage (Dfl/ha/year) caused by water shortage or excessive wet conditions. Using the method described in section 5.1 the MHGL, MLGL and the respectively corresponding damage caused by excessive wet conditions (water logging damage) and the damage due to water shortages (drought damage) have been calculated for the present situation and the different scenarios. In figures 15 and 16 the results are presented as absolute values for the present situation and changes compared to the present situation for the different scenarios. Appendix 6 shows the changes in MHGL and MLGL. Within these calculations, the soil type and land use have been taken into account. AGRICOM only computes drought and water logging damage for agricultural land use. Damage to forest and nature reserves is not taken into account.

The calculated MHGL and MLGL show approximately the same patterns: the shallow groundwater levels with a MHGL up to 0.5 m and MLGL up to 1.2 m are situated in the peat and clay areas in the northern and western part of the Netherlands. The deeper groundwater levels with a MHGL more than 1.0 m and MLGL more than 2.0 m occur in the areas with sandy soils. The changes in groundwater levels are described in more detail in section 5.1. As expected, the changes in drought and water logging damage follow the change in MHGL and MLGL. In the results of the scenarios, the patterns of the changes were less obvious due to the changes in land use. In areas where agriculture has been replaced by nature or urban area, the damage has been decreased to zero. These areas are presented in figure. In the figures presenting the results, the change of damage due to the replacement of agriculture by nature or urban areas are not presented.

Table 15 shows the absolute values (between brackets) of the drought damage, water logging damage and the sprinkling costs and the changes that may occur for the different scenarios. The values are given as total costs in millions DFL for the whole Netherlands and the mean value per hectare in Dfl/ha (table 16). In the present situation, the drought damage amounts to approximately 245 millions DFL for the Netherlands. The water logging damage is approximately 956 millions DFL and the sprinkling costs are about 96 millions DFL. Drought damage occurs especially in the higher sandy areas in the southern and eastern part of the Netherlands (damage occurs especially in areas with peat soils (Figure 18).

Table 15. Changes in drought damage, water logging damage and sprinkling costs summed for the whole Netherlands (Millions DFL). The values in brackets represent the total amount of damage in the present situation (REF1995).

Scenario	change drought damage (M DFL)	change in water logging damage (M DFL)	change sprinkling costs (M DFL)	total damage (M DFL)
REF1995	0 (256)	0 (956)	0 (96)	0 (1298)
REF2050	- 22	- 118	- 0,8	- 140.8
CEN2050	- 28	- 66	- 1,4	- 87.4
UPP2100	- 30	+ 44	- 1,2	+ 12.8

Table 16. Mean value of changes in drought damage and water logging damage for a hectare. The values in brackets represent the total amount of damage in the present situation (REF1995).

Scenario	change drought damage (Dfl/ha)	change water logging damage (Dfl/ha)
REF1995	0 (84)	0 (402)
REF2050	0	- 12
CEN2050	- 3	+ 13
UPP2100	- 4	+ 69

Autonomous developments

The autonomous developments cause a decrease in drought damage of approximately 22 Millions DFL, while mean amount of drought damage per ha remains the same. The decrease of drought damage in the reference scenario for 2050 may therefore be ascribed to the changes in land use. The replacement of agriculture by nature or urban area in this scenario has decreased the total area used for agriculture with 2360 km^2 and consequently the total drought damage on a national scale.

Water logging damage decreases with approximately 118 Millions DFL for the entire area of the Netherlands. However, the mean water logging damage for a hectare decreases with 13 fl. This is probably the result of the replacement of agriculture by nature in peat areas (wet conditions) as for example in the provinces Zuid-Holland and Friesland. These were areas with more water logging damage than on average. Consequently, the mean water logging damage decreases. In addition, a comparison of the distribution of the crop damage and land use changes indicates that the crop damage changes are caused by the changes of land use. This does not mean that the land subsidence will not have any influence on agriculture, because in the used modelling approach it was assumed that the water management would keep up with the land subsidence by adjusting the drainage depth.

Figure 34 and figure 35 indicate that the impacts of the autonomous developments for an individual farmer may be different at a regional scale. Conform the larger changes of MHGL compared to MLGL the impact on the water logging damage is larger. In these figures, the changes of water logging damage and drought damage are not presented in areas where the agriculture has disappeared. Apart from the replacement of agriculture by nature or urban area, a great deal of the changes in drought and water logging damage for REF2050 is also caused by changes in agricultural land use. For instance, a change from cereals into grass will cause more drought damage, because grass is a more water-demanding crop with a less effective root system. On the other hand, a change from grass into 'remaining agriculture' (often potatoes or sugar beets), will result in more water logging damage, because in general grass tolerates wetter conditions. These changes within the agriculture itself result in less water logging damage and more drought damage in mainly the provinces Zeeland and Flevoland and Noord-Holland.

Climate change

In general, climate change results in less drought damage and more water logging damage. The effects increase with more climate change. The central estimate for 2050 results in a total decrease of 28 Millions DFL of drought damage. Comparison with the reference scenario for 2050 indicates that a decrease of about 4 Millions DFL of the drought damage is caused by the higher groundwater levels induced by climate change. The mean drought damage decreases with 3 fl/ha, but again locally the changes may be different. Decreases of the drought damages occur mainly in areas with a large increase of MLGL, in the western part of the Netherlands. Climate change reduces the decrease of the total water logging damage caused by the autonomous developments (REF2050). The total water logging damage decreases with 66 Millions DFL. Climate change has increased the water logging damage with 52 Millions DFL (118-66), when compared to the reference scenario.

Within the upper estimate for the year 2100, the drought damage decreases with 4 fl/ha, which is approximately as is the central estimate for 2050. However, on a regional scale the changes are larger, especially when compared to the central estimate 2050. In polder areas of the Netherlands the drought damage increases. The larger differences between different areas result in approximately the same decrease of the total drought damage as the central estimate.

The total water logging damage, on the other hand, increases with 44 Millions DFL relative to the present situation. The rise of the MHGL has increased the water logging damage almost everywhere. Relative to REF2050, a temperature rise of 4 C has increased the total water logging damage with approximately 162 MFL (118+44). The most severe increases within this scenario occur especially in the northern areas of the provinces of Noord-Holland, Friesland and Groningen and the province of Zeeland. In these areas the total costs caused by excessive wet or dry conditions increase more than 200 Dfl/ha.

As mentioned before, the impacts on the autonomous developments and climate change may be different on a local scale and consequently different for the individual farmer. The changes of crop damage for different crops in table 16 show that, dependent on the crop type, the impacts may be larger than the average on table 17 indicates. Also the replacement of a certain type with an other type of agriculture may result in a different impact in a certain area than in general.

Table 17. Mean value of changes in drought damage and water logging damage per hectare for different crops (Dfl/ha).

Scenario	drought damage			water logging damage		
	grass	cereals	other	grass	cereals	other
REF2050	-2	+11	-7	-20	-21	+3
CEN2050	-3	+7	-11	-6	+9	+35
UPP2100	-3	+3	-15	+23	+76	+108

Sprinkling costs

Both the autonomous developments and climate change result in a small decrease of the total sprinkling costs, especially when compared to the damages caused by excessive wet and dry conditions. The decrease of the total area used for agriculture (changes in land use) reduces the total costs for sprinkling. More precipitation due to climate change results in higher groundwater levels and less demand for sprinkling. In the upper estimate for 2100 the sprinkling costs decrease less compared to the central estimate, due to the lower MLGL in the northern provinces. Because of the relative high invariable costs, the changes for sprinkling caused by climate change do not contribute significantly to the total sprinkling costs in the Netherlands. In addition sprinkling occurs mainly in the summer period, which has less increase or even a decrease of the precipitation.

Photo 2. Example of water logging damage for agriculture. High groundwater levels reduce crop growth and the use of heavy machines (RIZA).

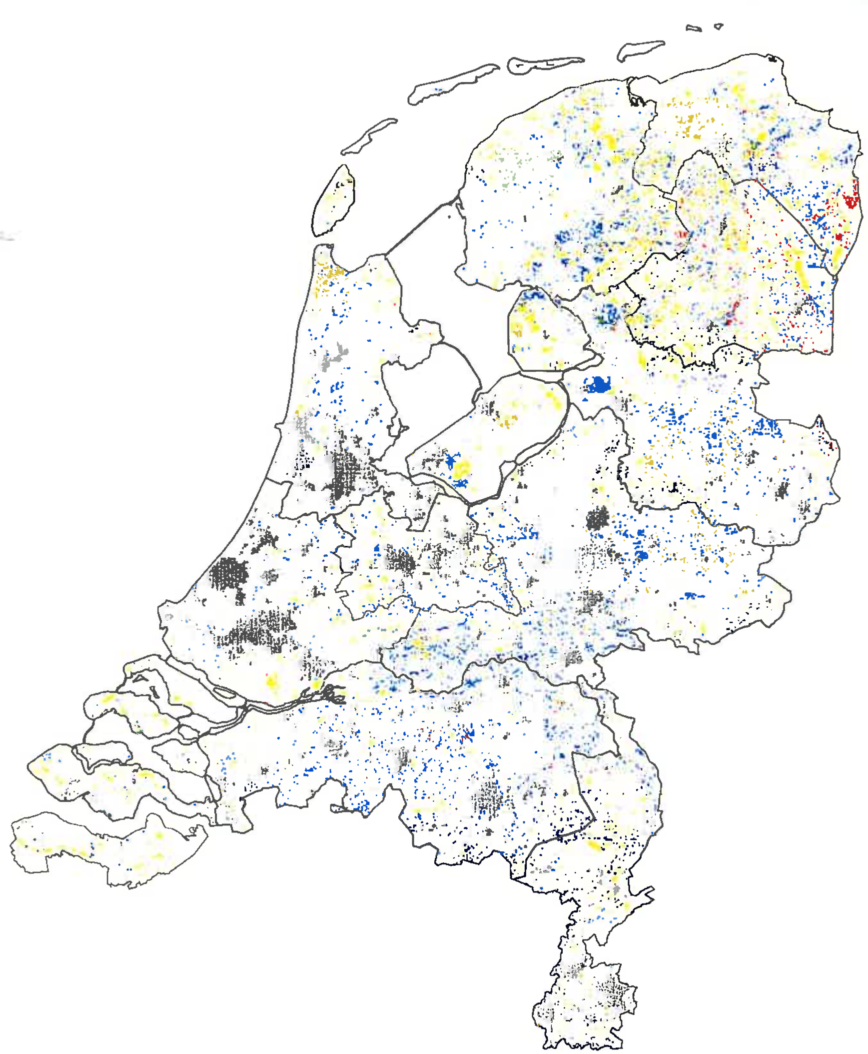


Figure 34. Change in drought damage for the reference scenario 2050 (REF2050).

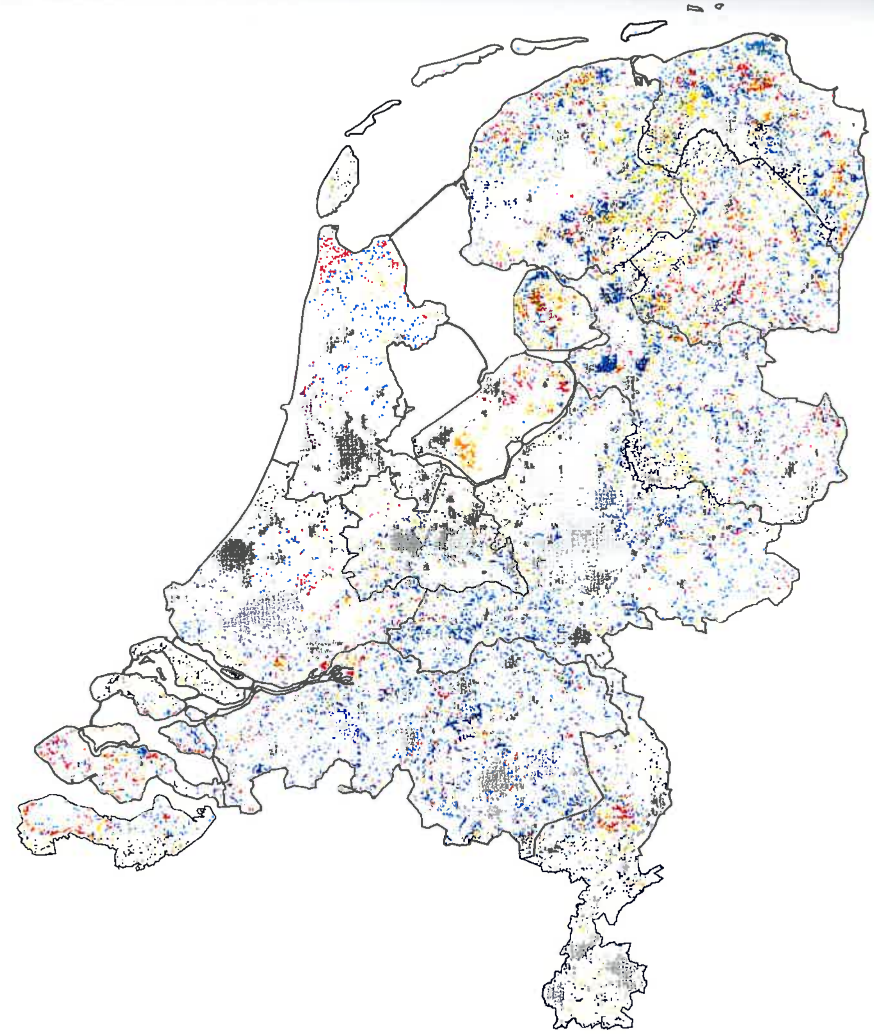


Figure 35. Change in water logging damage for the reference scenario 2050 (REF2050).

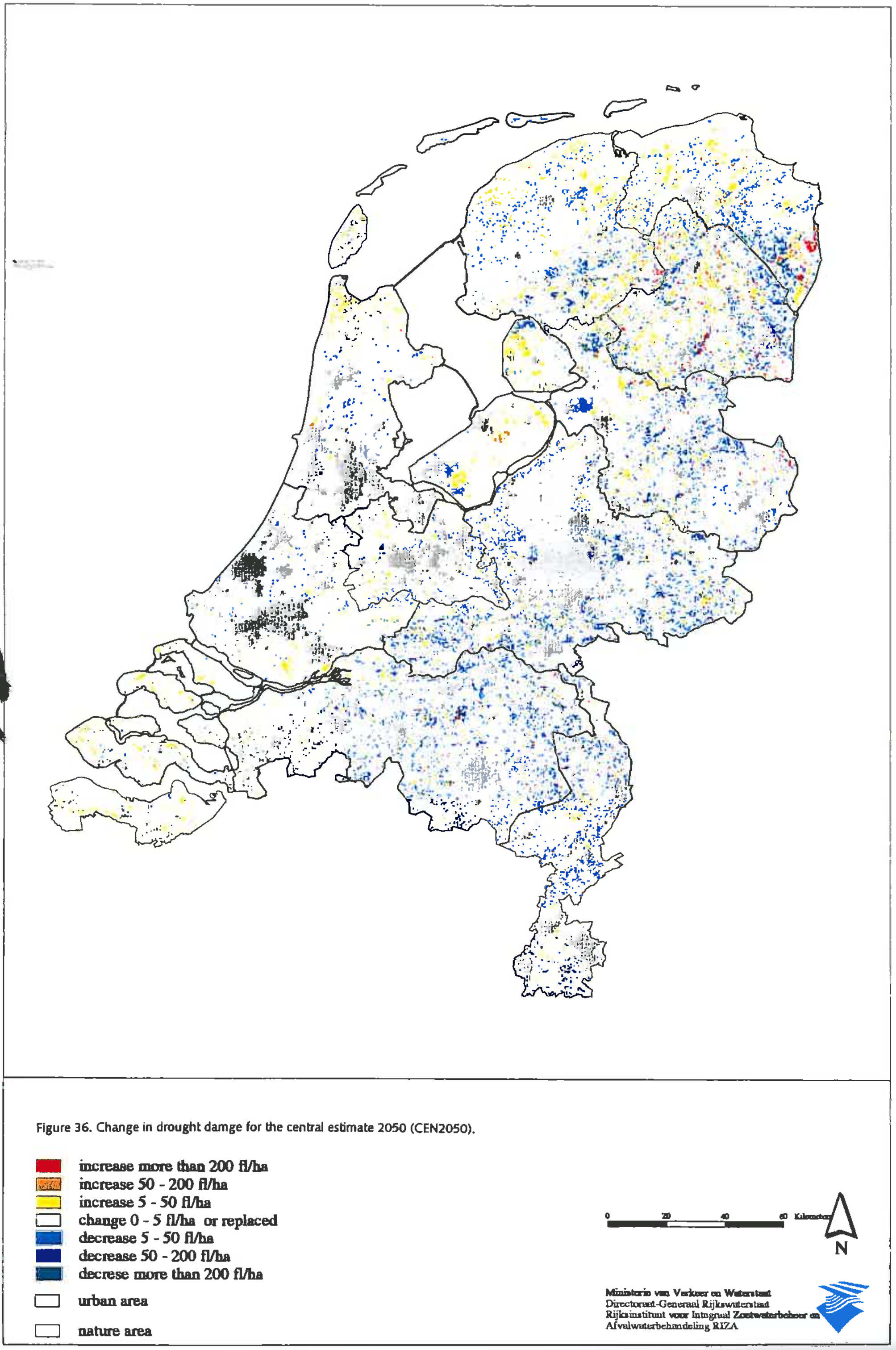


Figure 36. Change in drought damge for the central estimate 2050 (CEN2050).

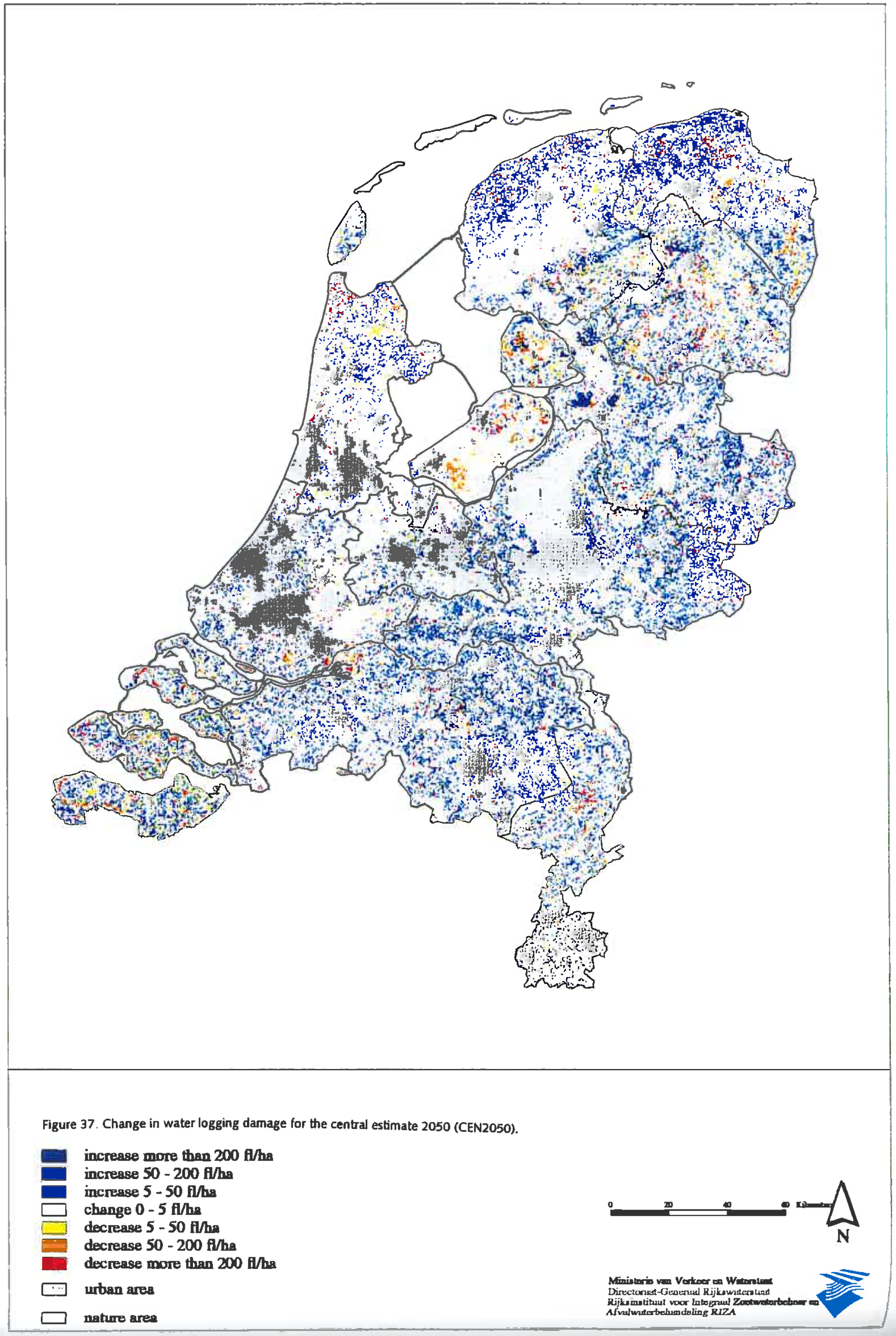


Figure 37. Change in water logging damage for the central estimate 2050 (CEN2050).

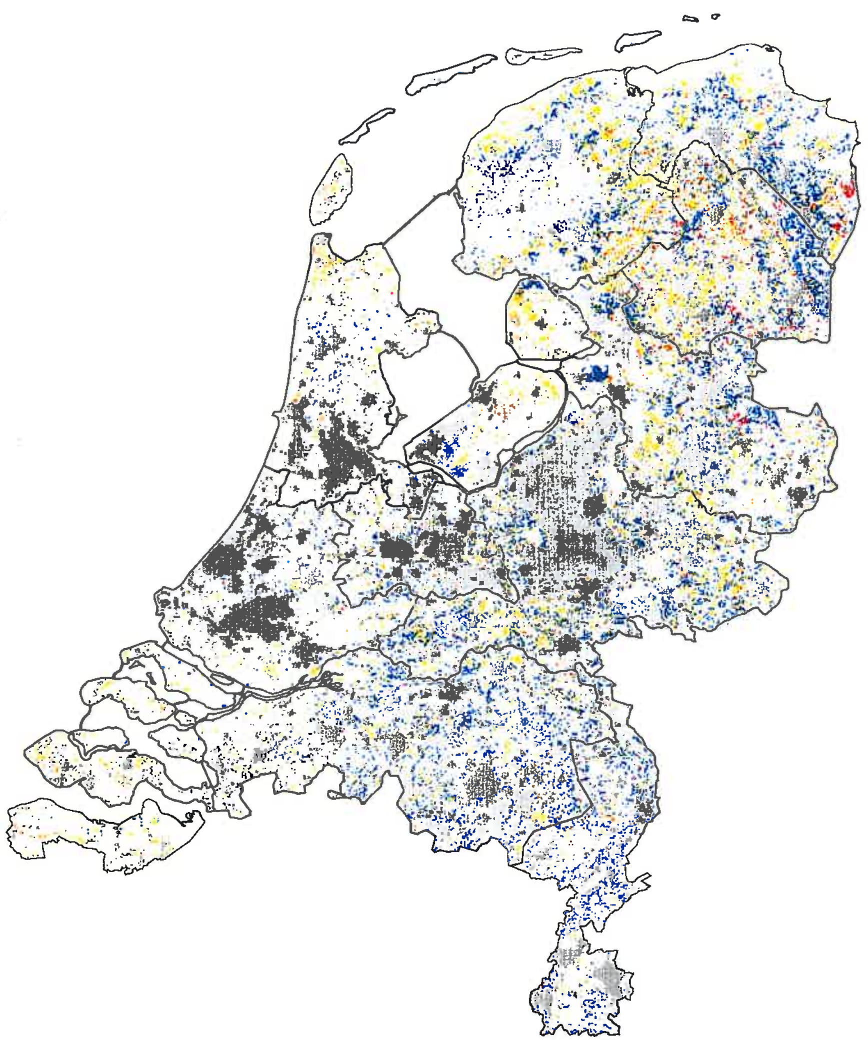


Figure 38. Change in drought damage for the upper estimate 2100 (UPP2100).

- increase more than 200 fl/ha
- increase 50 - 200 fl/ha
- increase 5 - 50 fl/ha
- change 0 - 5 fl/ha
- decrease 5 - 50 fl/ha
- decrease 50 - 200 fl/ha
- decrese more than 200 fl/ha
- urban area
- nature area

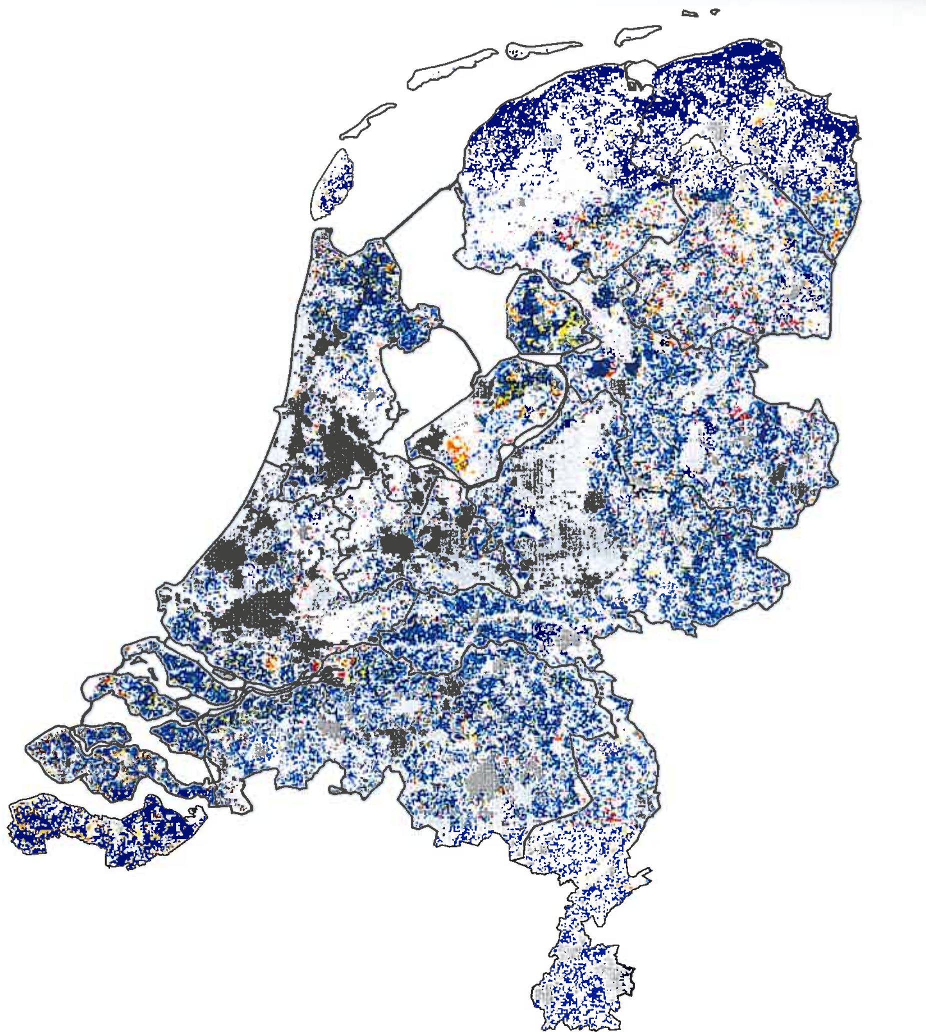


Figure 39. Change in water logging damage for the upper estimate 2100 (UPP2100).

- increase more than 200 fl/ha
- increase 50 - 200 fl/ha
- increase 5 - 50 fl/ha
- change 0 - 5 fl/ha
- decrease 5 - 50 fl/ha
- decrease 50 - 200 fl/ha
- decrease more than 200 fl/ha
- urban area
- nature area

5.3 Discussion

5.3.1 Impact on Nature

It is difficult to ascribe the changes in conservation values of the reference scenario for the year 2050 to either land subsidence or changes in land use. Comparison to earlier studies, where the impacts of land subsidence and changes in land use were quantified separately is an option. However, within this study, new (more actual) input files are used and the hydrological models have been calibrated. This has improved the hydrological output, especially in the province of Drenthe, but consequently also changed the hydrological doses.

For the eco-hydrological model DEMNAT small changes in the mean spring groundwater level will cause a large change in the conservation value, which is consistent to reality. Furthermore, the change of conservation value is the summed effect of the different ecotopes. Consequently, a small change of a hydrological dose will have a large impact on areas with a high conservation value in the present situation, like Drenthe. Both mentioned features of DEMNAT make it impossible to compare the scenario with all autonomous developments with the scenario where the impacts have been quantified separately in earlier studies (Kors *et al.*, 1997; Working group climate change and land subsidence, 1997).

According to modelling with the new insights, the autonomous developments may increase the total conservation values in the Netherlands. While the former studies for both land subsidence and changes in land use have resulted in a decrease of the conservation values on a national scale. The patterns of the changes in conservation value are more or less the same. To estimate the impacts on land subsidence and changes in land use on wet conservation values separately, the modelling of an other scenario is needed. This scenario should only include land subsidence or changes in land use.

The comparison of the changes in conservation value to a reference for maximum restoration, based on the TRENDBREUK scenario of the AQUATIC OUTLOOK, is a method to get an idea of the magnitude of the calculated changes. The TRENDBREUK-scenario assumes that the problems and potentials of different functions are managed in a structural way and as good as possible until the year 2045. In addition, the calculation of the maximum restoration is strongly related to the present conservation values. This may result in an overestimation compared to the real maximal feasible restoration. Furthermore, it is questionable if the TRENDBREUK scenario is the best hydrological scenario for maximum restoration. The use of the TRENDBREUK-scenario in this study is an attempt to understand the calculated changes of conservation values.

There are several aspects of the modelling which influence the modelled impacts and are worthwhile to mention is this discussion. The hydrological dose from DEMNAT includes the changes in the mean spring groundwater levels (MSGL). The value of the MSGL depends mainly on the MHGL. The larger differences between the groundwater levels in summer (MLGL) and in winter (MHGL) may therefore be less perceptible in the ecological changes. Especially in the upper estimation for the year 2100 the lowering of the MLGL may lead to lower conservation values than modelled. This in combination with the phenology of plant species may cause different ecological impacts. For example, the effect of dryer conditions in the summer may lead to unfavourable conditions for plants species, which have their germination in this period.

Furthermore, DEMNAT predicts only effects for the gridcells with enough information of the presence of plant species. The impacts are strongly influenced by the input of the present distribution of ecotopes. This is the reason of the relative small impacts in the provinces Friesland despite the significant hydrological changes.

The fact that ecological management is not included in the model may cause a general overestimate of the ecological impacts. The fertilisation of agriculture areas results in eutrofication and more nutrient-rich sites and less (more valuable) nutrient-poor sites than predicted. It may cause an underestimate of the development of nutrient-poor ecotopes in nature reserves that used to be agriculture but as a result of the changes in land use. A common used management is the decreasing of the nutrients, which increases the developments of highly appreciable nutrient-poor ecotopes.

Despite the above mentioned discussion points the modelled impacts of DEMNAT are indicative for the effects of autonomous developments and climate change and are especially useful when compared to results of DEMNAT (watersysteemverkenningen, 1997).

5.3.2 Impact on Agriculture

Autonomous developments

In the description of the results the decrease of the total drought damage has been ascribed to the land use changes, based on the absence of the mean change of drought damage for a hectare. The results of the study of working group climate change and land subsidence (1997) indicate that land subsidence has no impact on drought damage. In the study of the working group, a scenario was modelled to assess the impact of only land subsidence on agriculture. These results showed no change in drought damage and a decrease of 1 Millions DFL of the water logging damage due to land subsidence. On the contrary, from the results of the present study it is difficult to determine whether the decrease is caused by land subsidence or by the decrease of the total area with agriculture. Using the results of the working group, it can be concluded that the decrease of water logging damage in reference scenario for the year 2050 is mainly caused by the changes land use. The largest changes are caused by the replacement of agriculture by nature or urban area. In addition, the change of the cultivated crops from cereals to grass or other crops results in a considerable decrease of the wet damage.

As stated before damages caused by land subsidence are minimal. This does not mean that the land subsidence will not have any influence on agriculture. In both studies, it was assumed that the water management would keep up with the land subsidence by adjusting the drainage depth. When the surface water levels will not be adjusted to the land subsidence continuously, the water logging damage will increase considerably. Kors et. al. (1998) determined the drought and water logging damage for agriculture caused by land subsidence for five time-steps until the year 2045 for the province of Friesland. In this study, the surface water level was maintained until the drainage depth was reduced to 60 cm due to land subsidence. When a drainage depth of 60 cm is reached, the drainage depth is assumed to follow the land subsidence. The drought damage decreases with a maximum of approximately 1.5 millions Dfl and the water logging damage increases with a maximum of 7.5 millions Dfl in 2045. The decrease or increase of the damages diminishes in the period between 1995 to 2045, but the maximum will not be reached in 2045. This would be the case, when a drainage depth of 60 cm is reached. Because of the calculated crop damage by Kors *et. al*. it is recommended to do more research on the impacts of land subsidence with different intensities of water management on a national scale.

Climate change and autonomous developments

The scenarios REF2050 and CEN2050 indicate a decrease of 5 millions DFL of 0drought damage caused by a temperature rise of 1 °C. This value is approximately the same as was calculated within the study of the working group climate change and land subsidence (1997) for a scenario that included land subsidence and a temperature rise of 1°C. Within this study, the land subsidence and distribution of precipitation has been improved using the latest insights.

Within the central estimate for the year 2050, the total water logging damage decrease with 66 millions DFL. Compared to the reference scenario for the year 2050, climate change has increased the water logging damage with 51,4 millions DFL (118-66). This equals the value from the climate scenario of the working group climate change and land subsidence.

Scenario UPP2100 results in an increase of the total water logging damage with 44 millions DFL caused by the autonomous developments and land subsidence. Compared to the reference scenario climate change has increased the water logging damage with approximately 162 millions DFL (118+44). UPP2100 indicates a bit more total drought damage, but on a regional scale, the differences are larger.

The results indicate that climate change might be severe but changes in land use may not be neglected in estimations of future impacts on agriculture. The total damage on a national scale may even be more affected by land use changes than climatic changes. The results show less impact of the climatic scenarios (+1°C and +4°C) on the total drought damage than the autonomous developments (REF2050). A temperature rise of 4°C has more impact on the water logging damage than the changes in land use. Moreover, on a regional scale the impacts of climate changes are stronger, especially for the water logging damage.

Method

In this study, it is assumed that agriculture is static. On the contrary, agriculture will probably develop crops, which will be more resistant against excessive wet conditions. In addition, agriculture may choose to cultivate other crops as for example rise. Especially, at a temperature rise of 4 °C this may be realistic. Also, the drainage of water at a regional scale may be better developed through a larger intensity of ditches and artificial drains. The increase of atmospheric CO_2 may result in a considerable increase of the yield, which is not considered within this study. It is recommended to do more research on the impact of CO_2 increase on the crop yield.

The damages caused by excessive wet or dry conditions have been calculated using long-term yield depression fractions and IKC-tables. The advantage of this method is that the drought and water logging damage are determined with the same method. A disadvantage of this method is that the damages are determined for a mean hydrological situation, which is the result of the use of the mean highest and mean lowest groundwater levels, MHGL and MLGL (Bos *et al.*, 1997). According to the definition, the MHGL and MLGL are determined over a period of eight years. Within this study, the meteorological data of a mean year (1985) is used to shorten the modelling time.

6 Evaluation of the impact on water system functions

This section gives an evaluation of the impacts of the calculated hydrological changes for different water system functions. In addition, possible water management strategies and adaptation or mitigation measures are given. The following functions of the water systems have been considered:

- water management;
- agriculture;
- nature.

First of all it should be noted that the estimated impacts of future meteorological boundary conditions on the water systems in the Netherlands are quite uncertain. Therefore, the impacts should be interpreted as consequences of 'what-if' scenarios, rather than as real forecasts. When using the results for the definition of water management policy, these uncertainties should be taken into account. Policy strategies should be based on the range of effects that might occur.

The problems that may arise with respect to the functions mentioned above can be summarised in a few terms:

- *water management*: the increase of discharges during winter will enhance the risk of flooding, unless precautions are taken (such as increasing the capacity of pumping stations or creating extra water storage in the system). The effects on water management may have been underestimated in this survey, as the effects of climate change on the discharges of the rivers Rhine and Meuse have not been taken into account. During winter, higher discharges of these rivers may complicate the discharge from the different polder systems, and during summer, lower discharges will enhance the risk of water shortages in the different polder systems.
- *agriculture*: higher groundwater levels during winter and spring will result in an increase of water logging damage for agricultural crops. On the other hand, summer conditions may be dryer and will consequently result in a slight increase of drought damage.
- *nature*: in general, future conditions will be wetter. Therefore, desiccation problems will decrease in most areas. However, the relations between vegetation and its abiotic surroundings (hydrology, soil, atmosphere), are extremely complex. Focusing on the hydrological changes only is not sufficient for a reliable prediction of the impact of climate change on nature. Important influences that have not been taken into account are for instance the effect of temperature on mineralisation and the effect of changes in atmospheric CO_2 concentrations on competition between natural vegetation's.

The impacts for these sectors and possible strategies for adaptation or mitigation were based, in addition to the model results of the present study, on literature research and interviews with representatives from the different functions. In the interviews, the representatives have been asked for a reaction on the modelling approach and the results of the hydrological models and the computed effects on agriculture and nature. Furthermore, they were asked to point out additional impacts which were not included in the modelling.

6.1 Feedback on the autonomous developments

The predicted land subsidence (Figure 18) was considered by the provincial authorities as quite reliable to occur in the future and was in accordance to most of the measurements made by local water boards. In the northeastern of the Province Fryslan the mining activities on salt appeared to be not included in the soil subsidence boundary condition. Salt extractions near Harlingen cause a land subsidence of approximately 35 cm until 2005 in a radius of 3.5 km. Although quite severe, these types of land subsidence have not been taken into account because of their local impact.

Remarks were made on the fact that possible future water management, like adjusting the reclamation, might mitigate the severity of land subsidence in the peat areas of the Netherlands. Especially in agriculture areas which are converted to nature areas or a combination of agriculture and nature, wetter conditions will result in less land subsidence due to oxidation and settlement. This effect has already been taken into account, as land subsidence due to oxidation and settlement in (future) nature areas was assumed to be negligible. Verheul (1998) measured land subsidence rates in a peat reclamation area. Drainage depths of 70-80, 50-60 and 30 cm resulted in a land subsidence of approximately 13, 8 and 5 mm/year respectively. These measurements are quite similar to the assumptions that were made within this survey.

The reactions on the assumed changes in land use were variable. In the peaty areas of the provinces Noord-Holland, Zuid-Holland and Utrecht (Groene Hart), the changes are similar to autonomous developments already described by the Provincie Zuid-Holland and Zuidhollandse waterschapsbond (1998). Also the assumed crop changes (from cereals to grass) were considered realistic. In the Province Fryslan a large nature area is predicted based on the future implementation of the EHS (ecological development structure of the Ministry of Agriculture, Nature conservation and Fisheries). The provincial authority estimates a much smaller area of approximately 500 ha nature area to be developed. The major reasons for this smaller estimate are difficulties with respect to the acquisition of the land.

Other comments included the fact that some of the autonomous developments in land use are not entirely autonomic, because they are influenced by land subsidence and possible climate change. Decreasing land subsidence due to oxidation and settlement may be an important reason for creating more nature in peat reclamation areas. However, most of the developments in land use can indeed be considered as autonomic. Including changes in land use in the reference scenario for 2050 made the interpretation of the results of the scenarios rather difficult. Therefore, a scenario without changes in land use is recommended. This scenario is foreseen within the scope of the WINBOS-project (Haasnoot & Van Vliet, in prep).

6.2 Impacts on water management

The actual impact of the hydrological changes depends strongly on the present hydrological situation, margins in water management, infrastructure (bridges, sluices, dikes) and pumping capacity. Once infrastructure and pumping capacity appear to be insufficient, huge investments are required to insure safety. Also, drainage conditions and storage capacity of sewer systems in urban areas may become a bigger problem than it is nowadays.

The present distribution of salt load in the surface water has been compared to calculations and measurements of the province Fryslan. They appear to be more or less the same. The distribution of the changes in salt loads has been improved with a better information on the location of different polder units.

The impact of an increase of salt loads depends on the function and the availability of fresh water. Problems with an increase of the salt load will occur mainly in the western and northern part of the Netherlands. Areas which obtain fresh water from the large rivers (for example areas in Zuid-Holland obtain their water from the river Rhine) may be confronted with a shortage of fresh water in summer. Due to the predicted lower discharges of the rivers Rhine and Meuse during summer and the higher demand due to the higher evapotranspiration, water shortages may occur more frequently and possibilities for flushing may decrease. Areas along the dunes get there water from the dunes itself and will not have to deal with this problem.

Not only the amount of salt loads will be influenced by a sea level rise but also the pumping and sluice capacity. The foreseen problems caused by a rise of the sea level have already been included in the water management policy for the Province Fryslan. In Fryslan a rise of 30 cm reduces the sluice capacity by 15 %.

A change of the water levels of the lake IJsselmeer influences the pumping capacity of the surrounding polders. Lorenz et al. (1998) computed that the lake levels will increase in winter and decrease in summer. This will lead to a decrease of the pumping capacity in winter and an increase of the intake capacity in summer. However, the possibility of flushing of polders with fresh water will become more restrictive during summer.

According to the computations, discharges from rural areas will increase as a result of the foreseen autonomous developments and climate change. The dimensions of the present water system are based on the present peak discharges. To determine whether or not the water system can deal with the hydrological changes as calculated in the scenarios, information on changes in peak discharges is essential. This was done for urban areas in a previous study (working group climate change and land subsidence, 1997). They found that the predicted more intensified precipitation (Middelkoop *et al.*, 1999) will lead to a more frequently overflow of sewers. This increases the amount of waste products in the surface water. Not only the sewer system but also other aspects of the water system, like the capacity of the present boezem systems in the polders and the pumping capacity, are important for safety, agriculture or nature. If for example a peak discharge is to high to be discharged, areas will be flooded and result in water logging damage for agriculture or increase the amount of nutrients in a nature conservation area and consequently result in eutrophication.

As mentioned before this survey presents the changes of the average discharge for a year. Only a change of the peak discharges will cause drainage problems. This will probably occur in winter, because in this period of the year the precipitation increases the most. In addition, winter discharges of the rivers Rhine and Meuse will increase as a result of higher temperatures and higher precipitation. (Kwadijk, 1993). On the other hand, water shortages are likely to occur more often in summer, due to the expected lower discharges on the rivers Rhine and Meuse. In this period of the year water, less water will be available for flushing, sprinkling and maintaining surface water levels. This problem was recognised by the interviewee for the south-western part of the province of Zuid-Holland.

6.3 Agriculture

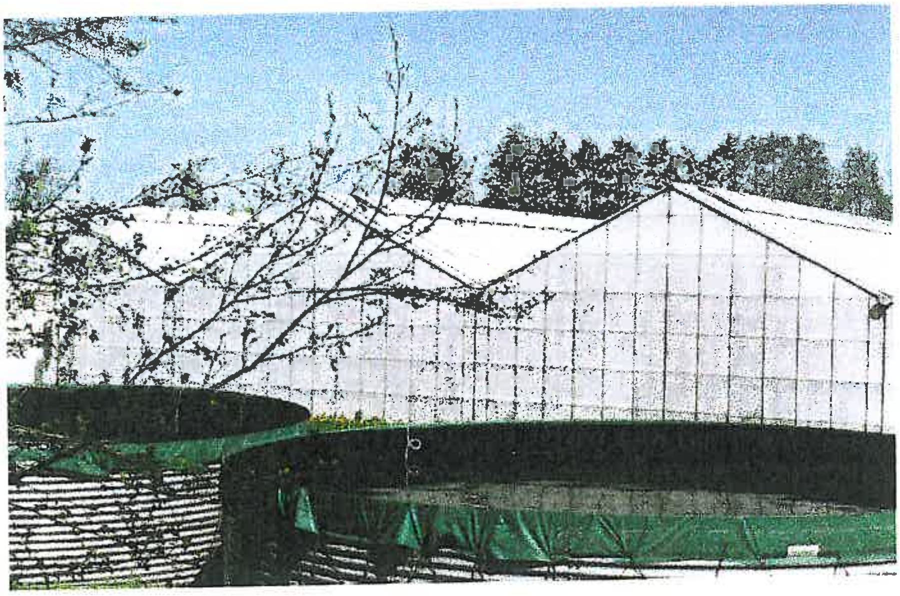
The estimated of damages for agriculture presented in this study were based on state of the art knowledge on the relation between groundwater regimes and drought and water logging damage. The severity of the drought or water logging damage depends on the rentability of a certain crop. A damage of 50 fl/ha is considered small when cultivating potatoes (relatively high profits), but large compared to the normal profit for cereals or bulbs. In general, for the reference and central estimate 2050, the computed damage was considered significant but not severe. However, for the upper estimate for 2100, the effects were considered quite severe. Especially, in the province Zeeland and the north of the provinces Fryslan and Groningen, the effects of water logging damage are larger than the changes in drought damage. To pass through the the dryer periods in summer larger rain bassins might be needed (photo 3).

The impact of an increase of salt loads depends on the cultivated crops. Greenhouse crops and bulbs exhibit the highest critical value of salt concentration with respect to salinity. Considerable salt damage occurs already at Chloride concentrations over 150 mg/l (see table 18 with salt concentration demands for different crops). For most greenhouse crops, this is no problem, because generally, these crops are already supplied with other sources than groundwater or surface water (rain bassins or drinking water). Bulbs are generally dependent on groundwater and surface water and these crops may suffer severe salt damage due to climate change, especially because these crops occur in parts in the west of the Netherlands where a considerable rise in salt loads is foreseen. The translation of the calculated salt loads to a concentration is complex. Depending on the amount of upward seepage, a salt load of 1000-200 kg/ha/year results in a mean chloride concentration in the surface water of 100-800 mg/l. A salt load of 500 kg/ha/year leads to a concentration of 50 - 200 mg/l.

Table 18. Critical value of salt concentration for different crops (mg/l).

Cultivation under glass/ bulb-growing	150
Drinking water humans	200
Vegetables/fruit	300
Grassland/arable farming	600
Drinking water cattle	2000

Photo 3. Larger rains basins might be needed when climate changes.



In the modelling approach, we assumed continuation of the present agricultural crops, methods and business planning. It is expected however that the agricultural sector will adapt to the changed environment (higher temperatures, higher CO_2 availability, wetter conditions). The foreseen wetter conditions may be mitigated by additional drainage measures. The increase of atmospheric CO_2 and temperature rise may result in a considerable increase of the yield (also that of conventional crops). This (considerable) increase in crop yields has not been considered in this survey. Under the foreseen conditions, alternative crops may become more interesting: crops that require higher temperatures (maïs, tabacco or even rice) and crops or variants of crops that are suitable for wetter conditions. Moreover a temperature rise of 1 °C corresponds with a latitude shift of some crops 100-150 km northward, which may also introduce other crops (Van de Geijn *et al.*, 1999). So, by adaptation of the present agricultural practice, the expected agricultural damage will be less severe.

Other effects, put forward by the experts from the agriculture sector not included in the modelling, are for example the fact that under the foreseen wetter conditions, grasses that appreciate wetter conditions will become more abundant. Often, these grasses contain fewer proteins. Consequently, farmers have to feed the cattle more power-fodder. In addition, continuation of the present business planning may become difficult, because planting and harvest times may change and it will become more difficult to decide when to manure in case of a more high intensity precipitation. Furthermore, wetter conditions may result in the loss off the early spring harvest of grass, which is the most important cut for farmers due to the richness of proteins. Also cattle has to stay longer in the stable. In both situations the farmer has to buy more power-fodder. In addition, milder winters could allow populations of agricultural pests and diseases to increase.

6.4 Nature

Wet terrestrial ecosystems benefit from a rise of groundwater levels, upward seepage and salt loads and a decrease in externally supplied water. Increased upward seepage and a reduction of the amount of externally supplied water, which is mainly originating from the Rhine, may improve water quality. Water originating from upward seepage has a better water quality for nature due to its longer retention time and enrichment in the soil.

A reduction of externally supplied water decreases the amount of phosphorous and nitrogen in the water in the different hydrological systems. It is generally known that these substances enhance eutrophication, which changes the nature of wetland and terrestrial communities radically. The nutrient-rich water reduces communities of rare highly valuable vegetation, which grow on sites with a low nutrient concentration. A reduction of externally supplied water will therefore increase the value of nature. Besides this, accelerated upward seepage extra salt loads from upward seepage might benefit nature, as highly appreciated brackish plant species will become more abundant.

One of the major environmental problems in the Netherlands is desiccation. In general, the extensive drainage of agricultural land and the extraction of groundwater cause this. The computed increase in groundwater levels might mitigate these desiccation problems. Figure 40 presents the desiccated areas with main or side function of nature. These areas are indicated as desiccated by the provinces (RIZA and IPO, 1999). The autonomous developments result in a rise of the mean spring groundwater levels in desiccated nature reserves in the dunes and peat areas in the province of Noord-Holland. The autonomous developments will also lead to wetter conditions in the brook valleys. On the Veluwe, the groundwater levels raise considerably in the nature reserves. In other nature reserves, the effect of the autonomous developments on the groundwater level is variable and only minor increases or decreases occur.

Photo 4. Wetter conditions increases the occurrence of wet terrestrial ecotopes. The photo shows Equisetaceae fluviatile (T. Garritsen)

The climate scenarios indicate a considerable rise of groundwater levels, which will have a positive effect on the ecology rare dune slacks. Also in the eastern and southern area of the Netherlands climate change might mitigate the desiccation problems. However, in some areas, the mean spring groundwater levels and the mean lowest groundwater levels drop, especially in the upper estimate for the year 2100. Consequently, desiccation problems might be enhanced, especially in the province of Friesland. In addition, areas adjacent to peat areas with a strong land subsidence, the lowering of the groundwater level could enhance desiccation problems (in Zuid-Holland). In the province of Noord-Holland near Amsterdam, the groundwater levels drop with approximately 0.5 -1.0 meter. In areas with a high drainage density, the mean lowest groundwater levels will drop, which indicates a lowering of the groundwater level in summer. It seems that in general the climate change may cause wetter conditions and mitigate the desiccation problems, but small areas may suffer damage as a result of a considerable drop of the groundwater levels.

Although it seems that the desiccation problems will disappear in most nature conservation areas, the problems will not be solved. Table 19 presents the changes of the mean spring groundwater levels in the desiccated areas. The actual impact on the desiccation problems depends on the present groundwater level. For example a rise of 5 cm in an area with very deep groundwater levels will have only minor effects, whereas a rise of 5 cm in an area with shallow groundwater levels may have a considerable effect. In most of the desiccated areas, groundwater levels rise with 0-5 cm. In most cases, this effect will be too small to solve the desiccation problems, because desiccation in most of the nature reserves has been caused by a drop of groundwater levels of approximately 30 cm. A rise of groundwater levels of 30 cm or more is only reached in a small part of the desiccated nature reserves. Therefore we can only conclude that nature reserves may suffer less from desiccation when the autonomous developments and climate change occur according to the calculated scenarios. In addition, Arp *et al.* (1998) found a positive effect of higher CO_2 concentrations on desiccation, because it stimulates growth under drought stress in nutrient-poor ecosystems.

Table 19. presents the distribution of the changes in mean spring groundwater levels in the desiccated areas in the Netherlands (%).

	< -5 cm	**-5 - 0 cm**	**no change**	**0 - 5 cm**	**5 - 10 cm**	**10 - 25 cm**	**> 25 cm**
REF2050	1.6	4.1	86.1	6.9	0.6	0.6	0.1
CEN2050	1.6	3.1	78.2	14.5	1.0	1.3	0.3
UPP2100	1.5	2.7	63.1	28.6	1.4	1.4	1.2

In the 'Vechtplassengebied' and the adjacent nature reserves of the Veluwe (western part of the province Utrecht), the increase of upward seepage due to climate change may improve water quality. In the nature area 'de Oostvaarders plassen' in the province of Flevoland the groundwater levels decrease as a result of the autonomous developments, which may change the present vegetation and fauna. In none of the present nature reserves the seepage changes from upward to downward seepage or vice versa. Consequently, the water quality will not change from precipitation water to seepage water or vice versa.

The autonomous developments result in a decrease of the salt loads in the peat areas of the province of Noord-Holland. This is a wet nature area with brackish vegetation. A decrease of salt loads may influence the abundance of vegetation. In Zeeland, the extra salt loads may stimulate the abundance of

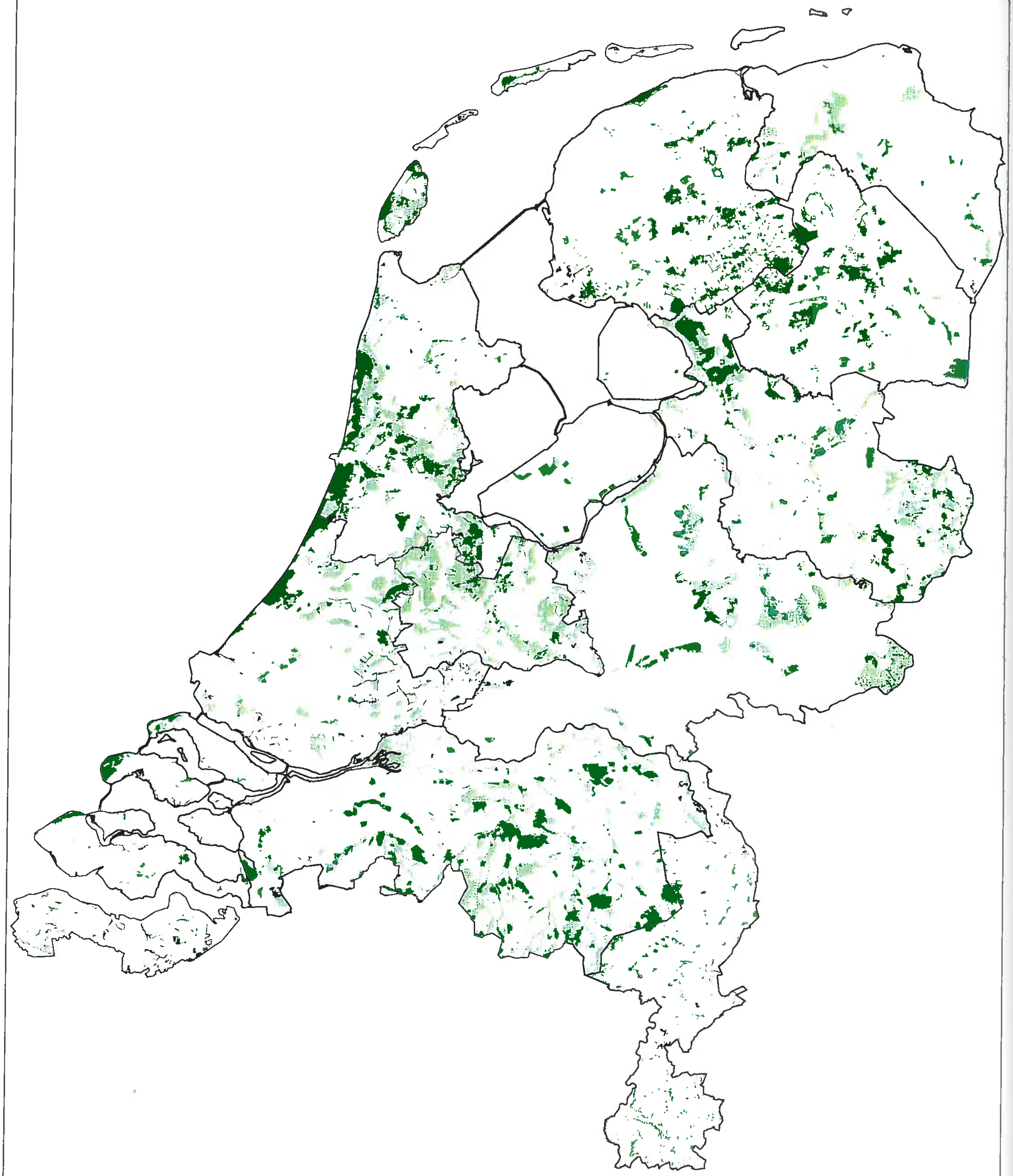


Figure 40. Dessicated nature in the Netherlands (RIZA and IPO, 1999).

main functions nature conservation
side function nature conservation

0 20 40 60 Kilometers

N

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Directoraat-Generaal Rijkswaterstaat
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brackish vegetation communities, which are highly appreciated. This occurs especially under the conditions according to the upper estimate for the year 2100. In addition, the autonomous developments result in a slight increase of the amount of externally supplied water and consequently result in higher nutrient concentrations in the surface waters. Therefore, the development of oligotrofe ecosystems will become more difficult in areas that are dependent on external water supply. Climate change results in a slight decrease of the relative amount of externally supplied water over a larger area (province of Zeeland and Holland, 'het Groene Hart') and might therefore have a positive effect on nature. Within the upper estimate for the year 2100, the amount increases again in the southwestern area of Holland.

In addition, other processes caused by climatic changes may influence the future quality of nature: more efficient photosynthesis, the disappearance and re-appearance of different plant species and changes in competition, depending on the optimum of photosynthesis, the availability of nutrients and the phenology of the plants. Some of these processes have been mentioned in section 4.4 and 5. The climate-induced increase of production due to a more efficient photosynthesis may be in the benefit of vegetation typical for nutrient-rich sites. By an increased growth, these plants will get benefit in competition. However, most of these plant species are less appreciated because of their common occurrence. Arp *et al.* (1998) concluded that these negative effects of increased nitrogen concentration will be stimulated by increased atmospheric CO_2 concentration as it causes an increase of biomass.

Moreover plant species with a C_3 photosynthesis will benefit more from the CO_2 rise than C_4 species, which will also change the composition of vegetation. Higher temperatures result in an increase the mineralisation of soil organic matter, can increase the nutrient richness of the soil. This may influence the succession and composition of the several ecosystems. Especially in those where these environmental processes are controlled by the rate at which the system acquires nutrients, like heather (Van de Geijn *et al.*, 1998).

6.5 Possibilities of mitigating measures

While looking for possible measures it is important to know what kind of hydrological situations we will accept in the future and what the future standards will be. Different solutions can be considered:

- accept the hydrological changes and consequently accept that some areas will flood with a specific frequency;
- adapting the function of a water system function;
- mitigate adversative effects by taking technical measures in water management such as increasing the capacity of pumping stations or intensifying the drainage of agricultural areas.

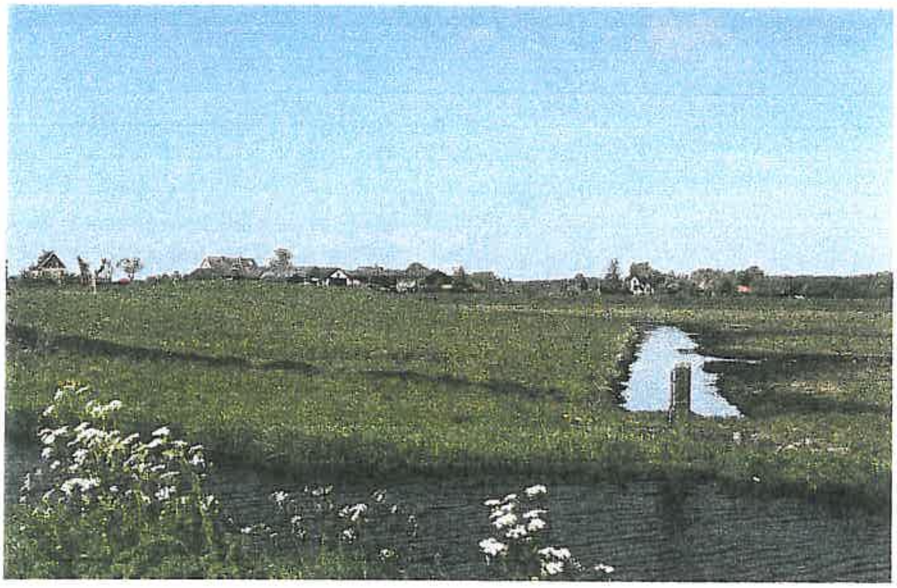
It would be irrealistic to chose for one of these solutions, the optimal solution may probably be found in a combination of the three solutions. The options can also influence each other. For example, if too many technical precautions would be necessary for a specific water system function, adaptation of the function and move the present function to another area might be a better solution. On the other hand some hydrological changes can also be accepted to occur for a certain function once in a while. Best precautions are those which serve different purposes and are useful anyway (apart from the expected climate change).

Water conservation and retention and creating inundation areas may be useful measures against problems with water shortage and flooding. Inundation areas offer more storage capacity and may therefore prevent flooding or will at least result in a less severe flooding. Inundation areas can be created by choosing polders or nature areas with only minor consequences of flooding. Usually, the water storage capacity of soils in agricultural areas is larger than that of wet nature reserves. However difficulties and damage might occur when large amounts of surface water would be stored in these areas. Another possibility for creating extra storage capacity is to enlarge the boezems in a polder area. An example of a more technical, probably efficient, but less sustainable measure to mitigate the risk of flooding is to increase the capacity of pumping stations.

An options for agriculture, where the hydrological changes are being accepted, is to search for secondary income like agricultural nature conservation and recreation. Especially, wetter conditions may contribute to these two secondary incomes. Agricultural nature conservation can include conservation of the side of ditches, protection of bird's nests, delay of grass cutting and creating wet situations for birds to forage. An example is given in photo 5. The farmer inundates part of his land for several weeks of the year. This attracts a lot of birds and increasing the biodiversity of plants. The dike is made especially for to make inundation of the land possible.

Furthermore, the cultivation of other crops (grassland tolerates wetter conditions) can also reduce the damage. To mitigate the effects of wetter conditions, the drainage intensity could be improved. This might however increase drought damage for agricultural crops in summer and enhance the problem of desiccation of nature.

Photo 5. Example of agricultural nature conservation.



A remedy against higher salt concentrations is a more intensive sprinkling and flushing. In these areas already fresh water is submitted to make the surface water suitable for agriculture. As mentioned before it might become difficult in the summer period when shortages of fresh water will occur more often. In addition, for greenhouse crops, the (already existing) water reservoirs can be enlarged (photo 3). Increasing the surface water levels when possible increases the pressure against the salt upward seepage. Draining directly to the sea and a better transport system of water could also mitigate the intruding salt from the sea. In addition one could avoid cutting impermeable layers when digging ditches and drains. However the drainage of most district water boards along the coastline does not occur by gravity. Another technical measure like, filtrating the groundwater can also reduce the salt concentration. This results however in a very salty remnant which will be injected in a deeper groundwater layer. However, this only defers the problems. A more sustainable development against the increased salt loads would, accepting the increase and adapt the water system function by the cultivation of salt tolerant crops or switching to other functions, like nature or recreation.

A lot of these measurements need space, which will be more and more scarce with all the socio-economic developments, especially in the western part of the Netherlands. More research will be done on the impacts and effectiveness of different measurements and strategies in a follow up of this survey.

7 Conclusions

7.1 Effects of autonomous developments

The autonomous developments have a variable effect on the groundwater levels. The average shows no changes. However, in 18 % of the total area the groundwater level decreases with more than 5 cm. Changes occur especially in areas where the land subsidence is considerable and where the change in land use causes a large change in evapotranspiration. Effects occur especially in the Veluwe area, the province of Friesland and the coastal dunes. Changed elevation gradients due to land subsidence cause a change in upward and downward seepage. An increased elevation gradient at the borderline between Holocene and Pleistocene area results in more upward and less downward seepage in the Holocene area. In the reclaimed lakes in the Holocene areas, the infiltration and upward seepage decrease.

In approximately 86 % of the total area, the discharge changes (increase or decrease) with 0 - 5 % in comparison with the present situation. Changes occur especially in 'het Vechtplassengebied' where the discharge increases with 10 - 20 %. Changes in salt loads are mainly caused by land subsidence and occur mainly in the western and northern part of the Netherlands.

Effects of autonomous developments on functions

The reference scenario for the year indicates a slight increase in conservation values on a national scale. On a regional scale, the changes may be significant. In the province Drenthe, the conservation values decrease due to unfavourable hydrological changes. Also in the areas adjacent to areas with land subsidence, the conservation value decreases due to the lower groundwater levels.

The autonomous developments have a considerable effect on the drought and water logging damage; respectively a decrease of approximately 22 millions DFL and an increase of 118 millions DFL. The results and a study of the working group climate change and land subsidence (1997) indicate small or no effects of land subsidence on the drought and water logging damage. This does not mean that the land subsidence will not have any influence for agriculture. In both studies, it was assumed that the water management would keep up with the land subsidence by adjusting the drainage depth. When it is assumed that the drainage depth will only be adjusted when reaching a certain level, the impacts of land subsidence will be significant. On the contrary, the changes in land use have large impacts on the total drought and water logging damage for the Netherlands. The calculated sprinkling costs show only a small decrease.

7.2 Effects of climate change

Climate change results generally in a rise of the groundwater levels. Within the central estimate for the year 2050, the mean spring groundwater level increases with an average of approximately 4 to 5 cm. Within the upper estimate for the year 2100, the groundwater level increases with an average of 10 to 15 cm. In areas with a high drainage density, the mean lowest groundwater levels decrease, which indicates a lowering of the groundwater levels in the summer period. The increase in precipitation results in a significant increase of infiltration in infiltration areas and an increase of upward seepage in areas with upward seepage. More precipitation within the upper estimate for the year 2100 results again in more infiltration and upward seepage. The increase in temperature and change in precipitation and evapotranspiration does not have a considerable impact on the salt loads. It is probably only the sea level rise that increases the salt loads in the province Zeeland. The increase in salt loads within the upper estimate for the year 2100 is caused by the assumed double land use. Climate change results in a significant increase in average annual discharges: approximately 12 % for CEN2050 and 25 % for UPP2100.

Scenarios REF2050 and climate scenarios CEN2050 and UPP2100 learned that changes in precipitation and evapotranspiration have considerably more effects on hydrology than the autonomous developments. As the effects of climate change on the measured hydrological parameters appear to be non-linear; the results can not be interpolated linearly for other scenarios.

Effects of climate change on functions

Climate change results in a significant increase of the conservation values in almost the whole country. Furthermore, the ecotopes will occur in a larger area then before climate change. A higher increase of the temperature results in more net precipitation and therefore in a better development of the wet terrestrial vegetation. The decrease of the conservation values induced by the autonomous developments has more or less disappeared in the climate scenarios.

Wetter conditions, as predicted by the models will decrease the desiccation problems in most areas. However, these problems will not be solved as the 'background desiccation' for the Netherlands is approximately 30 cm and the average increase of the groundwater level in nature conservation areas, calculated by the models, is less than 5 cm. Besides the hydrological changes, nature will be influenced by the CO_2 and temperature rise. Both may influence the composition of the vegetation.

For agriculture, the climate scenarios indicate an increase of the water logging damage and a decrease of drought damage. This effect increases with more climate change. However, on a regional scale the changes may be different due to the different hydrological changes caused by climate change but also due to the land use changes like the replacement of agriculture by nature, urban area or a different crop and the different properties of crops. Within the CEN2050 scenario, the total drought damage for the Netherlands decreases with 26 millions DFL, from which approximately 5 millions DFL is due to a temperature rise of 1 °C. A stronger climate change has not so much more impact on the total drought damage for the Netherlands. Although the total amount of drought damage does not change, on a regional scale the change of drought damage may be significant.

Climate change results in an increase of the water logging damage. A temperature rise of 1 °C increases the total water logging damage for the Netherlands with approximately 51 millions DFL. A stronger climate change, as modelled in the upper estimate for the year 2100, increases the total water logging damage with 160 millions DFL. The increases occur almost everywhere, but especially in the north and eastern area with agriculture.

The sprinkling costs show only small changes within the calculated climate scenarios. The decrease of the total damage caused by the autonomous developments diminishes with a stronger climate change. This is caused by the three times more water logging damage in the upper estimate for 2100 compared to the central estimate for 2050.

The results indicate that climate change might be severe but changes in land use may not be neglected in estimations of future impacts on agriculture at a national scale. The severity of the calculated damage for the individual farmer depends on the rentability of a certain crop. Not only the hydrological changes will influence agriculture, but also the rise of the CO_2 concentration and temperature.

Impacts on water management depend strongly on the present margins in water management. Problems include mainly the capacity to discharge water to prevent flooding in winter and to get fresh water for sprinkling and flushing in summer.

7.3 Possibilities of mitigating measures

Possibilities of mitigating measures can be found in accepting, adapting or mitigating the hydrological changes caused by the autonomous developments and climate change. The first two kinds of measurements are more sustainable. Examples of these precautions are: agricultural nature conservation, water storage and inundation areas, cultivation of other crops or changing the water system function. Measures which mitigate the impacts of wetter conditions are for example: increasing the drainage intensity and pumping capacity.

8 Recommendations

Recommendations on the modelling

- Within the model calculations was assumed that the supply of water in summer is not limited. For climate change, longer periods of drought are expected, which may cause lower availability of Rhine water in summer. This may cause an overestimate of the groundwater levels. The relative amount of the demand of externally supplied water shows small changes for climate change. The assumptions of no limitations in water supply may therefore have minor impacts on the results. However, climate change results also in considerable changes in discharges of the rivers Rhine and Meuse. Therefore, it is recommended to do calculations taking the water limitation and the changes in discharges from the rivers into account.
- On the average the effect of climate induced changes in transpiration on the groundwater level seems small. A deviation of the change of a few percentages will not have a great influence on the groundwater level. However, when the errors become larger, the effect on groundwater level may become more severe, especially compared to the results of the scenario calculations. The predictions for the change in crop are quite unsure. It is therefore recommended to do more research on the impact of an increase in temperature and CO_2 in total evaporation and especially on the change in transpiration.
- The results show the average impact of climate change. It should be taken into account that the local effect may be different. This may have a great impact on the functions. It is therefore recommended to do more research on a local scale.

- The modelling of the crop damages would be more realistic if the damage is determined every decade and not from the mean highest and mean lowest groundwater levels. Then the damage would be less than the average for several years. This kind of modelling needs development of the water-logging damage module in MOZART.
- Within this study the land subsidence has no or a small impact on the total crop damage of the Netherlands. This is the result of the assumption that the water management will keep up with the land subsidence. When the surface water levels will not be adjusted to the land subsidence continuously, the water logging damage will increase considerably. It is therefore recommended to do more research on the impacts of land subsidence with different intensities of water management on a national scale.
- Because of the difficulty of the interpretation of the results of the reference scenario for the year 2050. It is recommended to model the impacts of land subsidence and changes in land use separate with the same input files as used within this study.

Recommendations on research on climate change

- The hydrological changes (especially the increased discharges) due to climate change have a considerable impact on functions and water management. A solution might be to adjust the function to a specific area and to make use of the hydrological changes caused by climate change.
- The results indicate the changes in land use are not negligible in modelling the future to estimate the impacts of for example climate change.
- When changes in land use have such a large impact on the total crop damages of the Netherlands, they may be one of the solutions in diminishing the impacts of climate change.
- When using the results for the definition of policy, the earlier mentioned uncertainties should be taken into account and policy strategies should be based on the range of effects that might occur.

Appendix 1. Land subsidence

Classification soil types (Provincie Friesland, 1997).

		thickness peat (cm)		
		0 - 40	40 - 120	> 120
thickness clay (cm)	0 - 10	sand	peat	deep peat
	10 - 40	clay on	peat on clay	
	40 - 120 > 120	sand	clay on peat	

Relation between rate of subsidence (mm/yr), soil type and reclamation (Provincie Friesland, 1997).

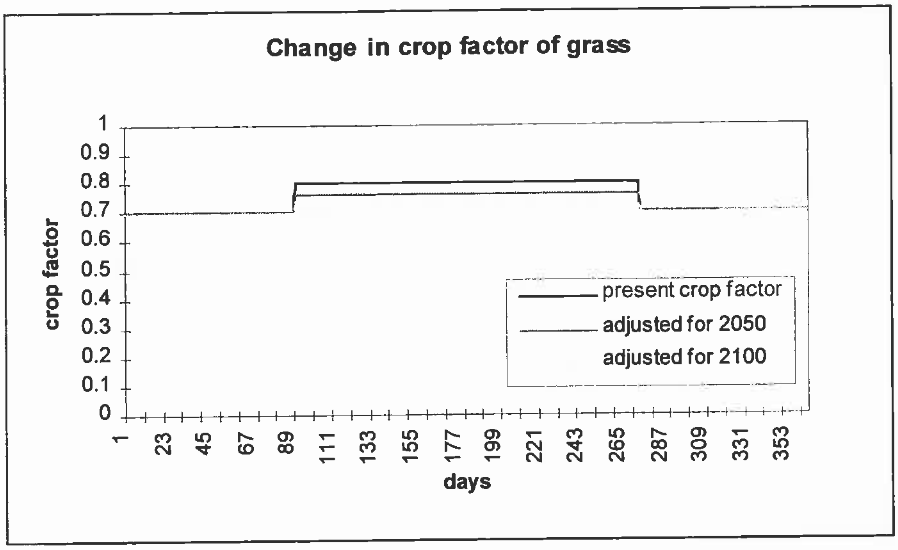
Reclamation		Soil type						
min	max	deep peat	peat	10-40 cm clay on peat	40-80 cm clay on peat	80-200 cm clay on peat	clay	clay on sand
0.00	0.00	1.60	1.25	0.80	0.45	0.20	0.07	0.05
0.10	0.20	0.30	2.50	1.60	0.90	0.40	0.14	0.10
0.20	0.30	4.26	3.44	2.42	1.50	0.75	0.24	0.17
0.30	0.40	5.18	4.28	3.16	2.03	1.05	0.32	0.20
0.40	0.50	6.10	5.03	3.84	2.53	1.35	0.40	0.27
0.50	60.00	6.93	5.67	4.37	2.97	1.59	0.47	0.32
0.60	0.70	7.64	6.27	4.87	3.39	1.81	0.53	0.37
0.70	0.80	8.28	6.84	5.31	3.73	2.00	0.29	0.42
0.80	0.90	8.87	7.37	4.73	4.04	2.19	0.65	0.46
0.90	1.00	9.42	7.86	6.13	4.32	2.38	0.70	0.49
1.00	1.10	9.91	8.32	6.54	4.60	2.55	0.75	0.52
1.10	1.20	10.37	8.77	6.92	4.86	2.72	0.81	0.56
1.20	1.30	10.80	9.20	7.27	5.10	2.88	0.86	0.60
1.30	1.40	11.18	9.52	7.56	5.31	3.01	0.90	0.63
1.40	1.50	11.56	9.83	7.80	5.51	3.13	0.93	0.65
1.50	1.60	11.95	10.14	8.11	5.00	3.24	0.96	0.67
1.60	1.70	12.26	10.40	8.33	5.87	3.33	0.98	0.69
1.70	1.80	12.50	10.60	8.50	6.00	3.40	1.00	0.70
1.80	>	12.73	10.79	8.66	6.13	3.47	1.02	0.71

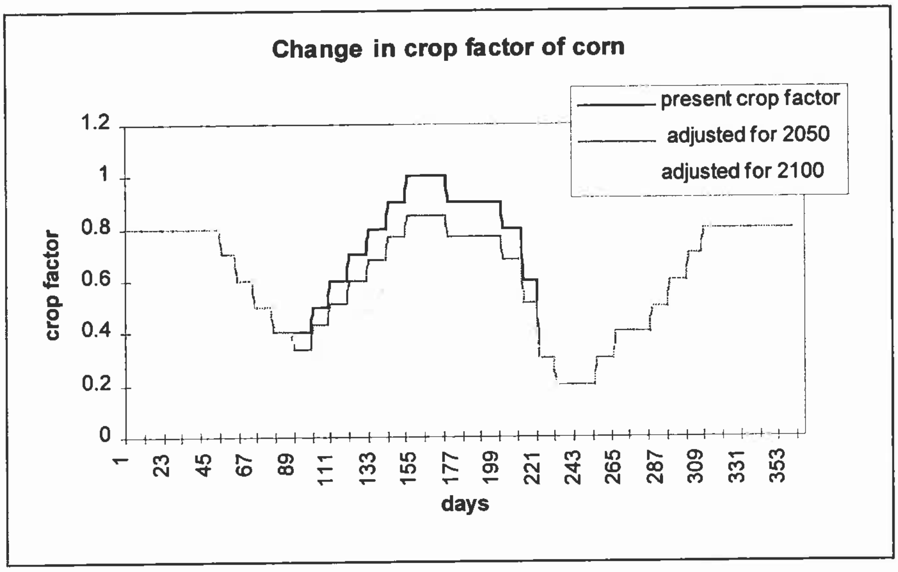
Appendix 2. Changes in temperature and precipitation

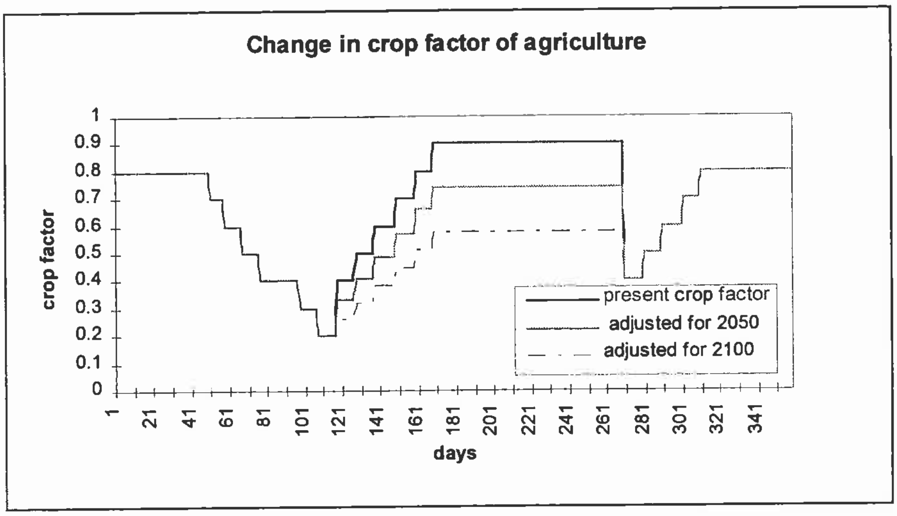
(Working group climate change and land subsidence, 1997)

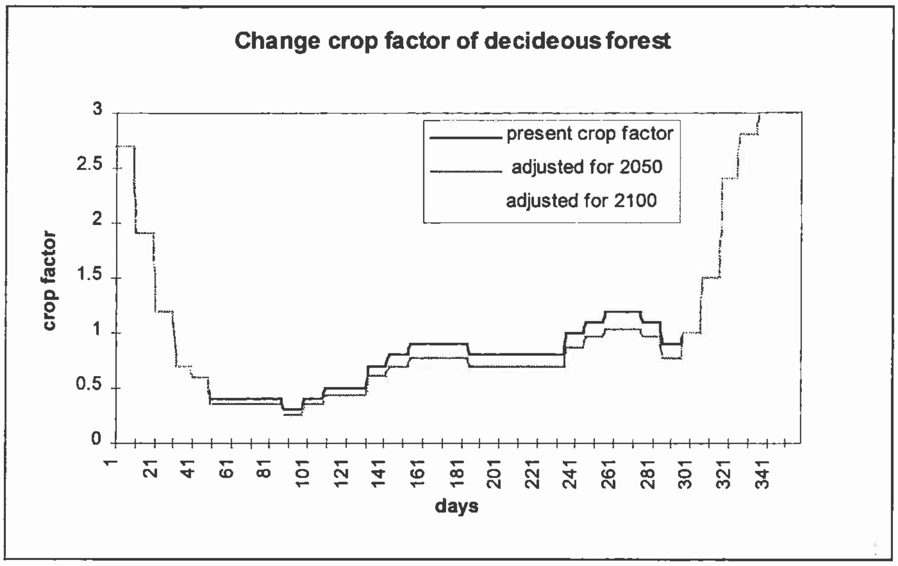
	CEN2050	UPP2100
temperature	+ 1 °C	+ 4 °C
precipitation over the year	+ 3 %	+ 12%
precipitation in summer	+ 1 %	+ 4 %
precipitation in winter	+ 6 %	+ 25 %
precipitation intensity in rain	+ 10 %	+ 40 %
long precipitation period in winter	+ 10 %	+ 40 %
frequencies of storm	+/- 5 %	+/- 5 %

Appendix 3. Change in crop factor with climate change during the year.

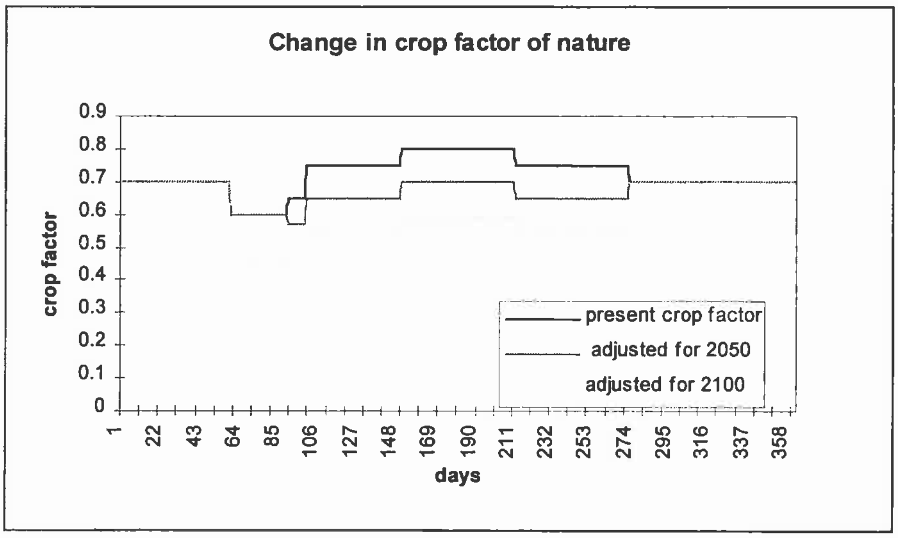






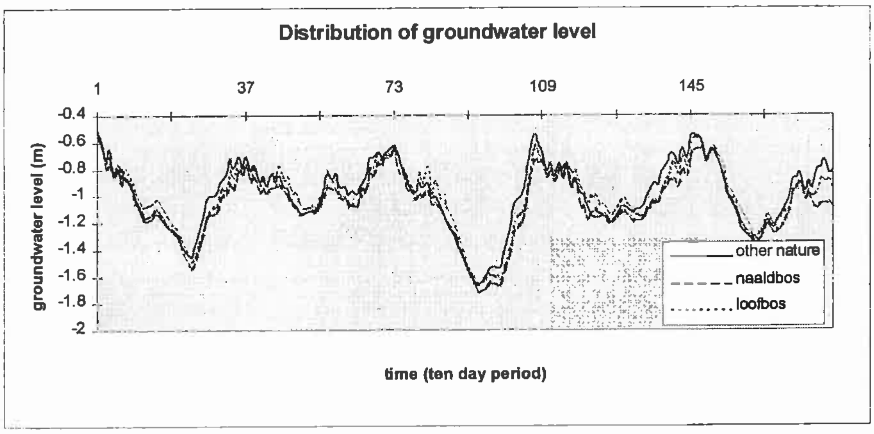


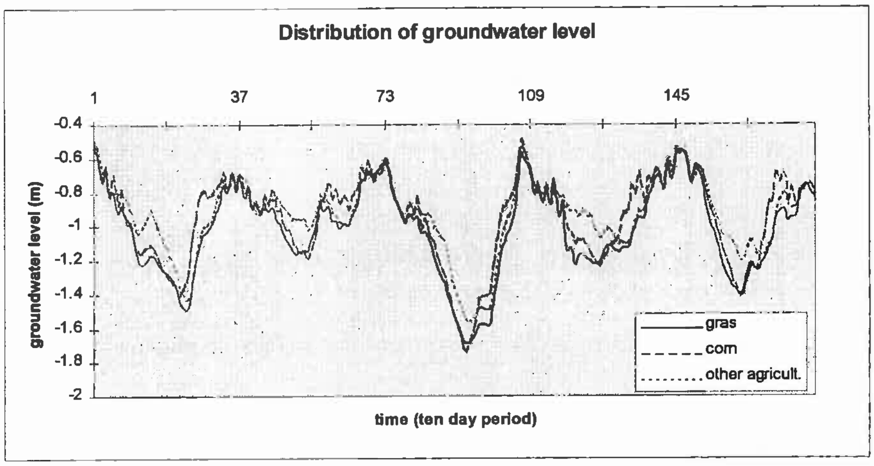
Change crop factor of decideous forest
present crop factor
adjusted for 2050
adjusted for 2100
crop factor
3
2.5
2
1.5
1
0.5
0
1
21
41
61
81
101
121
141
161
181
201
221
241
261
281
301
321
341
days

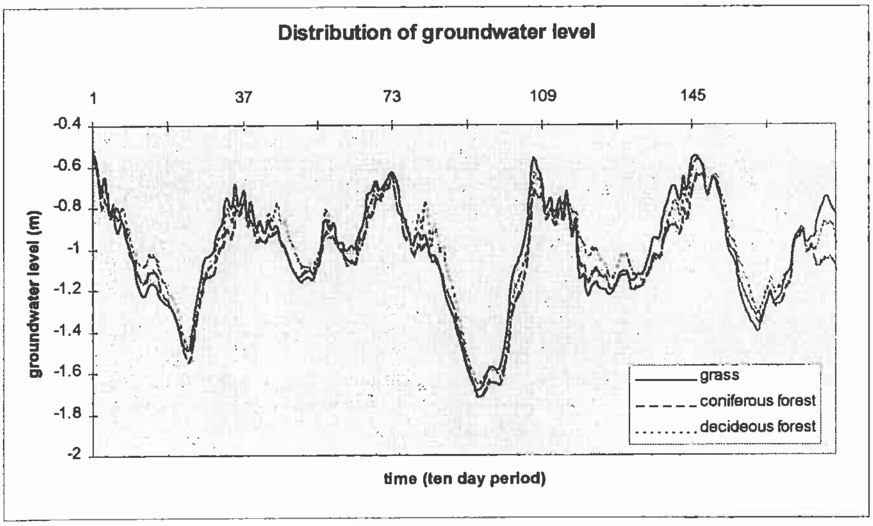


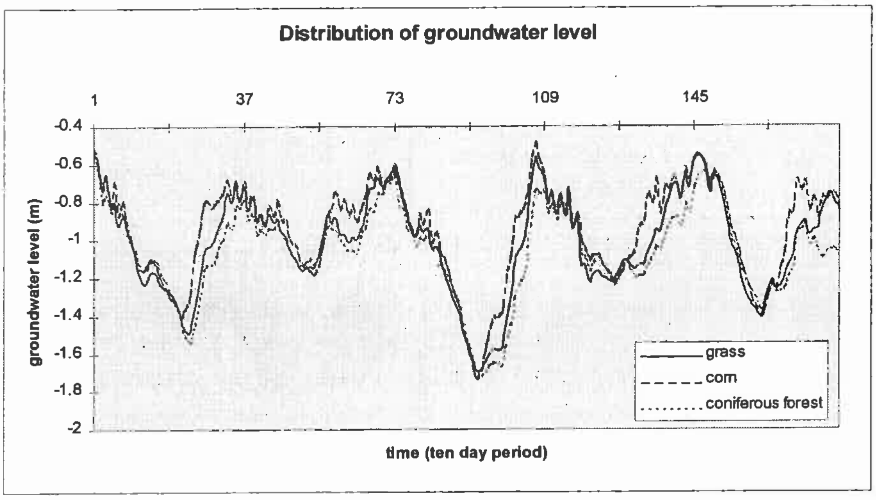
Change in crop factor of nature
present crop factor
adjusted for 2050
adjusted for 2100
crop factor
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
22
43
64
85
106
127
148
169
190
211
232
253
274
295
316
337
358
days

Appendix 4. Distribution groundwater level over the year for different crops.



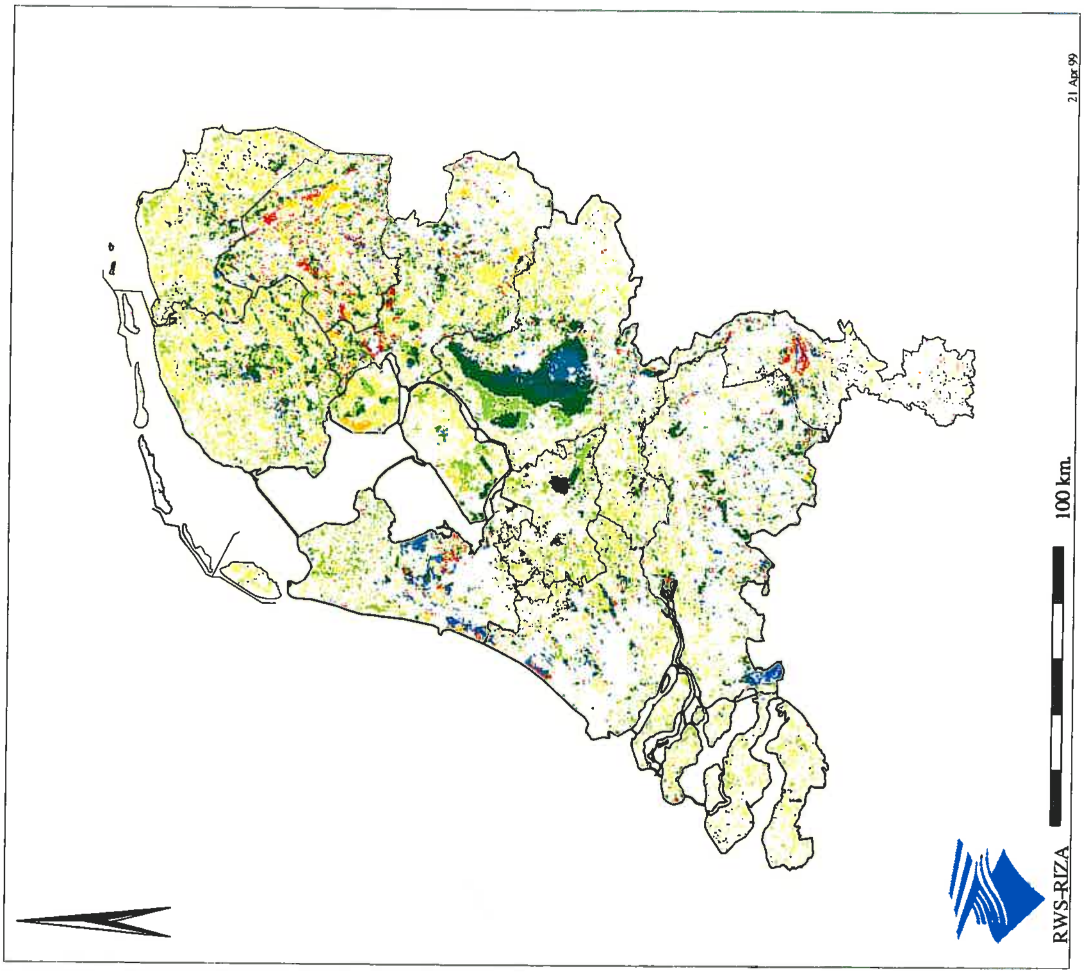




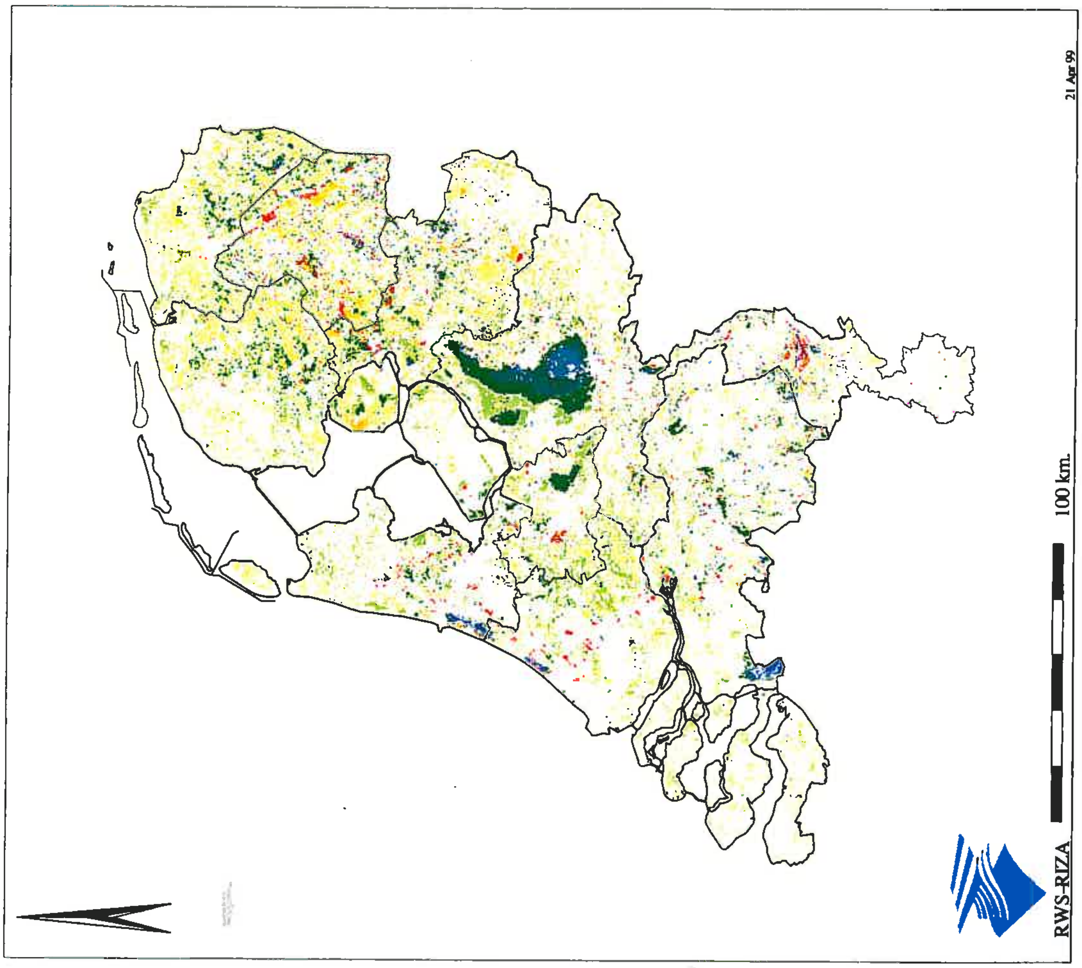

Distribution of groundwater level
1
37
73
109
145
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
groundwater level (m)
grass
corn
coniferous forest
time (ten day period)

Appendix 5. Provinces in the Netherlands.

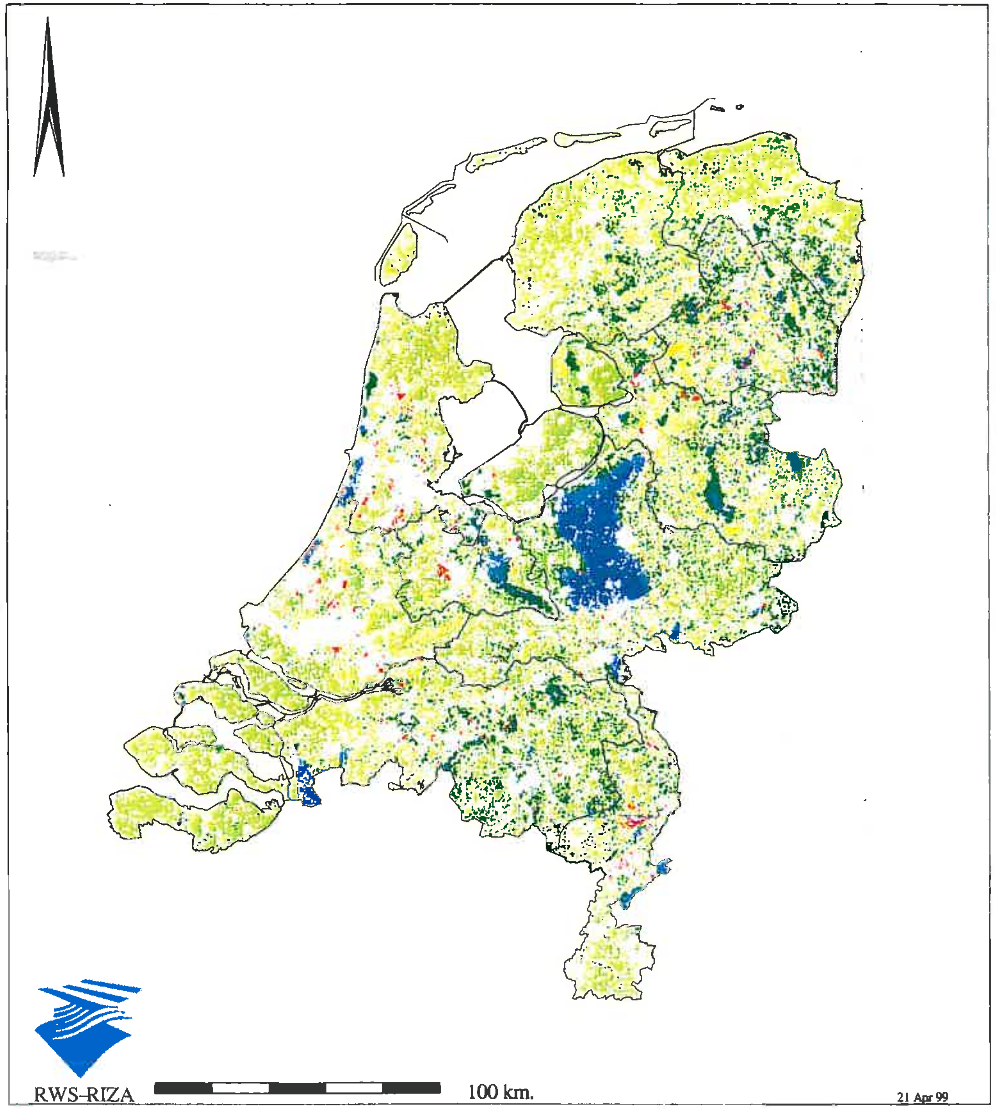
Appendix 6. Changes in MGHL and MLGL.



Change in mean lowest groundwater level for the reference scenario 2050.

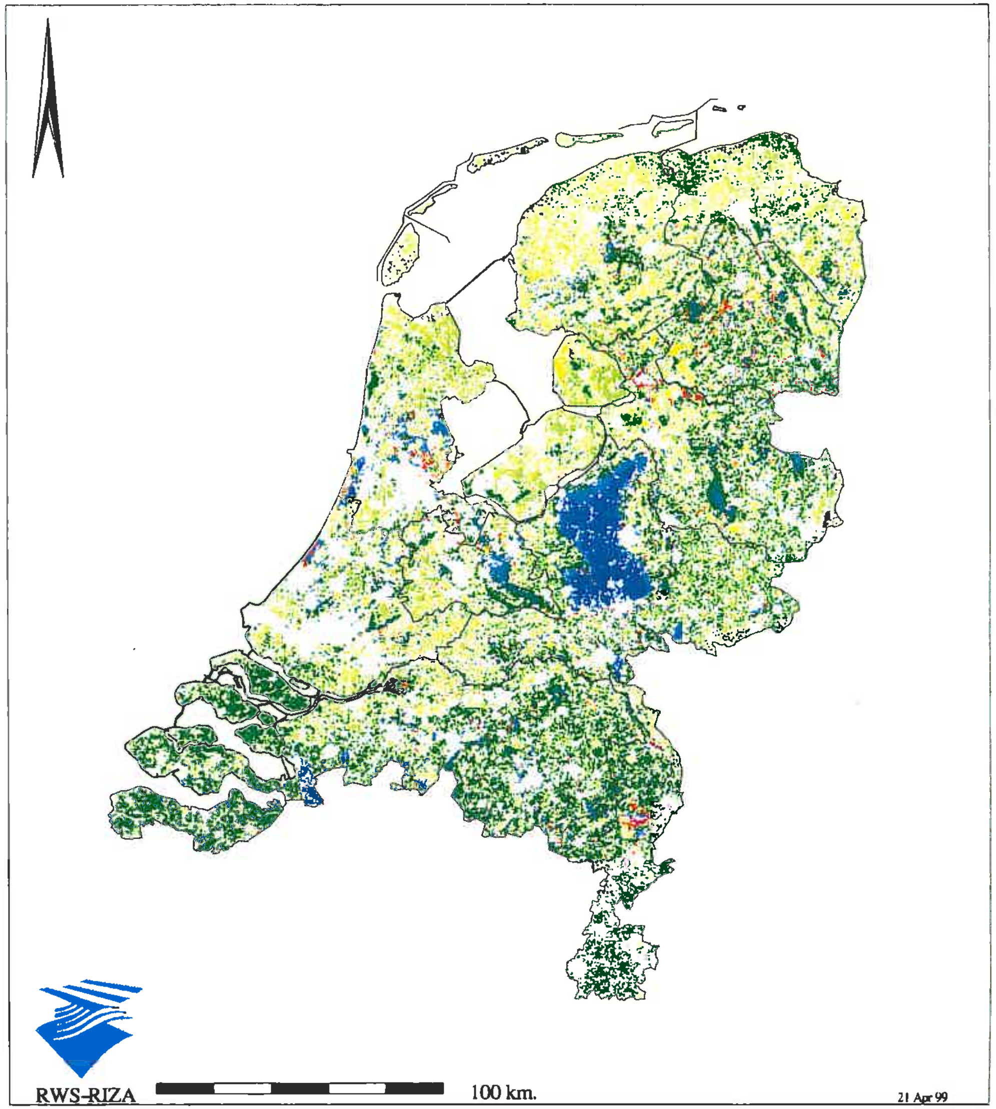


Change in mean highest groundwater level for the reference scenario 2050.



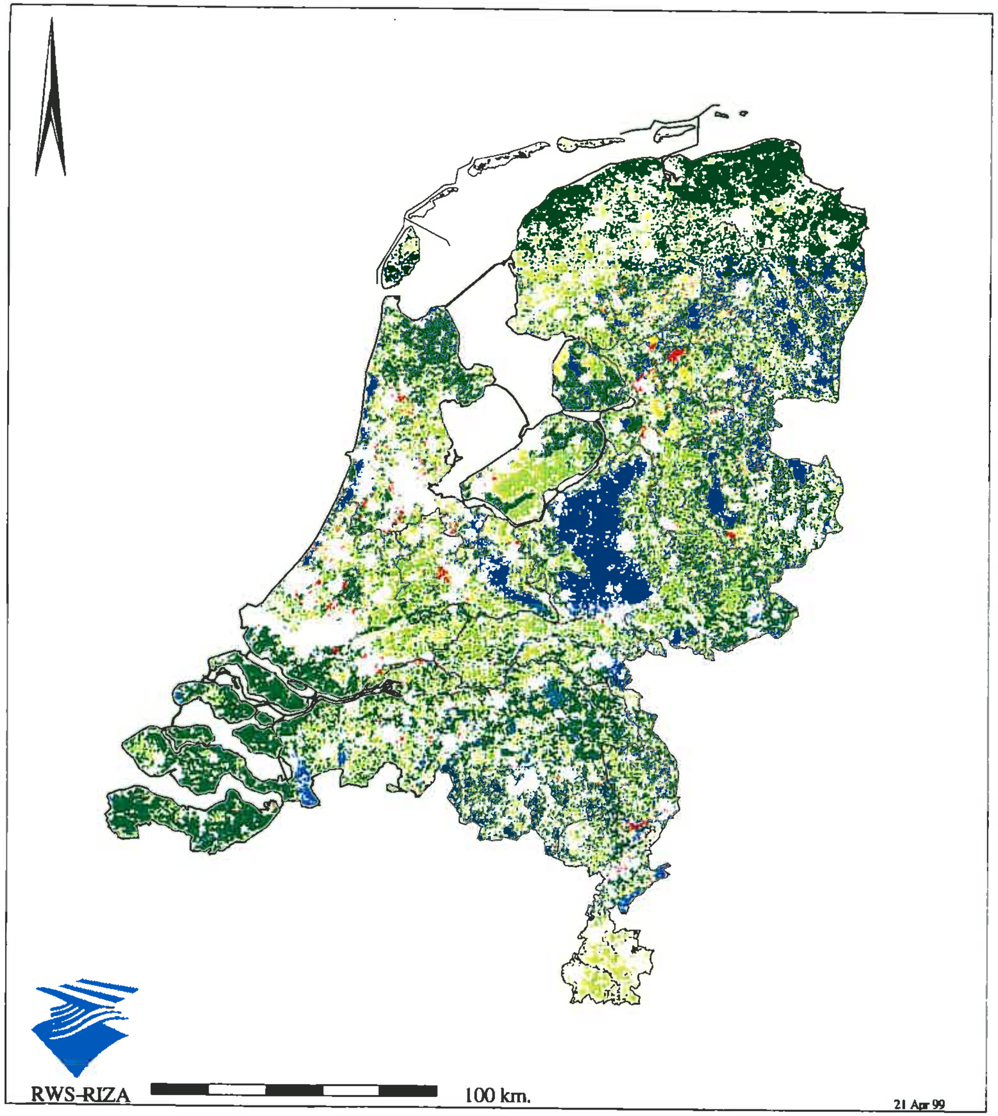
Change in mean highest groundwater level for the central estimate for the year 2050.

decrease more than 1 m	increase 0.00 –0.10 m
decrease 0.5 –1.0 m	increase 0.10 –0.25 m
decrease 0.25 –0.50 m	increase 0.25 –0.50 m
decrease 0.10 –0.25 m	increase 0.50 –1.00 m
decrease 0.00 –0.10 m	increase more than 1 m
no change	



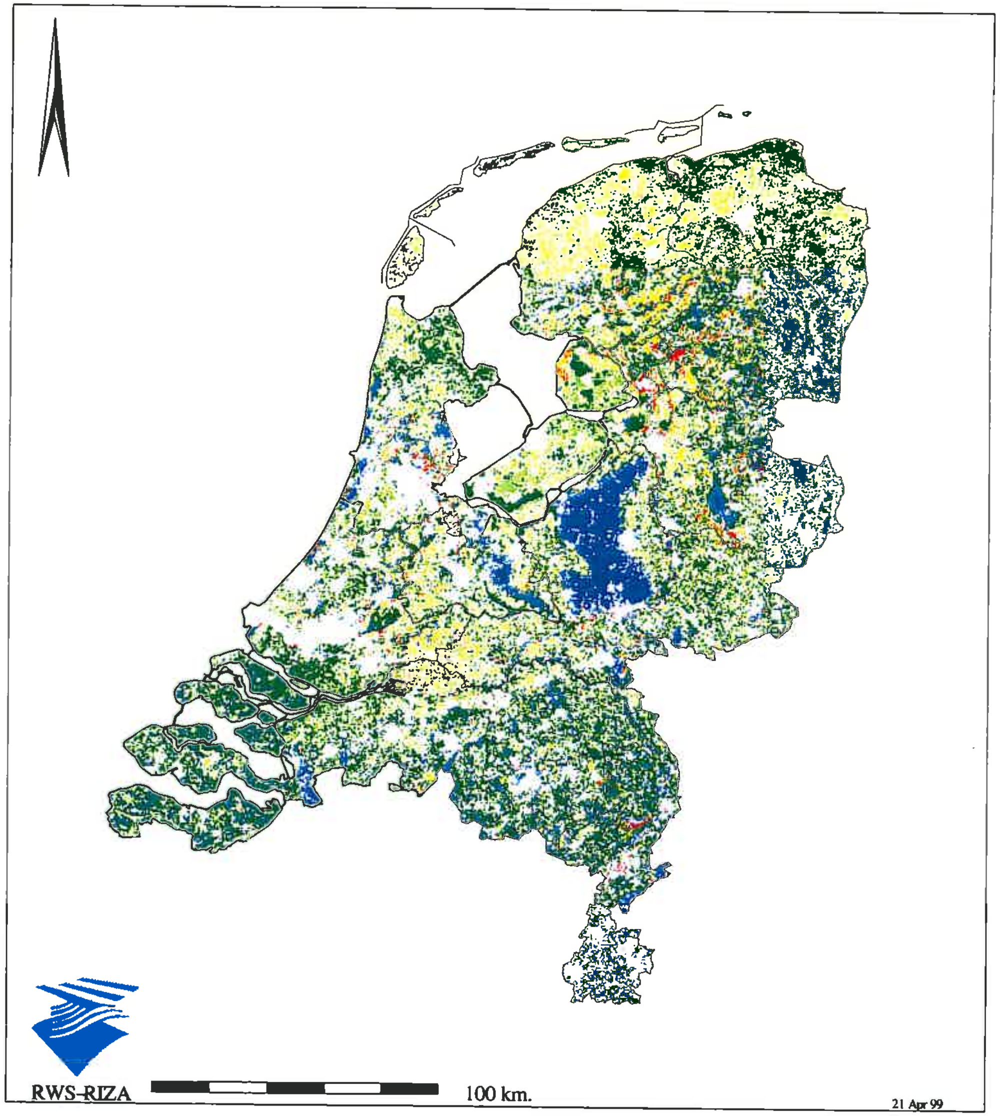
Change in mean lowest groundwater level for the central estimate for the year 2050.

decrease more than 1 m	increase 0.00 –0.10 m
decrease 0.5 –1.0 m	increase 0.10 –0.25 m
decrease 0.25 –0.50 m	increase 0.25 –0.50 m
decrease 0.10 –0.25 m	increase 0.50 –1.00 m
decrease 0.00 –0.10 m	increase more than 1 m
no change	



Change in mean highest groundwater level for the upper estimate for the year 2100.

- decrease more than 1 m
- decrease 0.5 – 1.0 m
- decrease 0.25 – 0.50 m
- decrease 0.10 – 0.25 m
- decrease 0.00 – 0.10 m
- no change
- increase 0.00 – 0.10 m
- increase 0.10 – 0.25 m
- increase 0.25 – 0.50 m
- increase 0.50 – 1.00 m
- increase more than 1 m



Change in mean lowest groundwater level for the upper estimate for the year 2100.

- decrease more than 1 m
- decrease 0.5 – 1.0 m
- decrease 0.25 – 0.50 m
- decrease 0.10 – 0.25 m
- decrease 0.00 – 0.10 m
- no change
- increase 0.00 – 0.10 m
- increase 0.10 – 0.25 m
- increase 0.25 – 0.50 m
- increase 0.50 – 1.00 m
- increase more than 1 m

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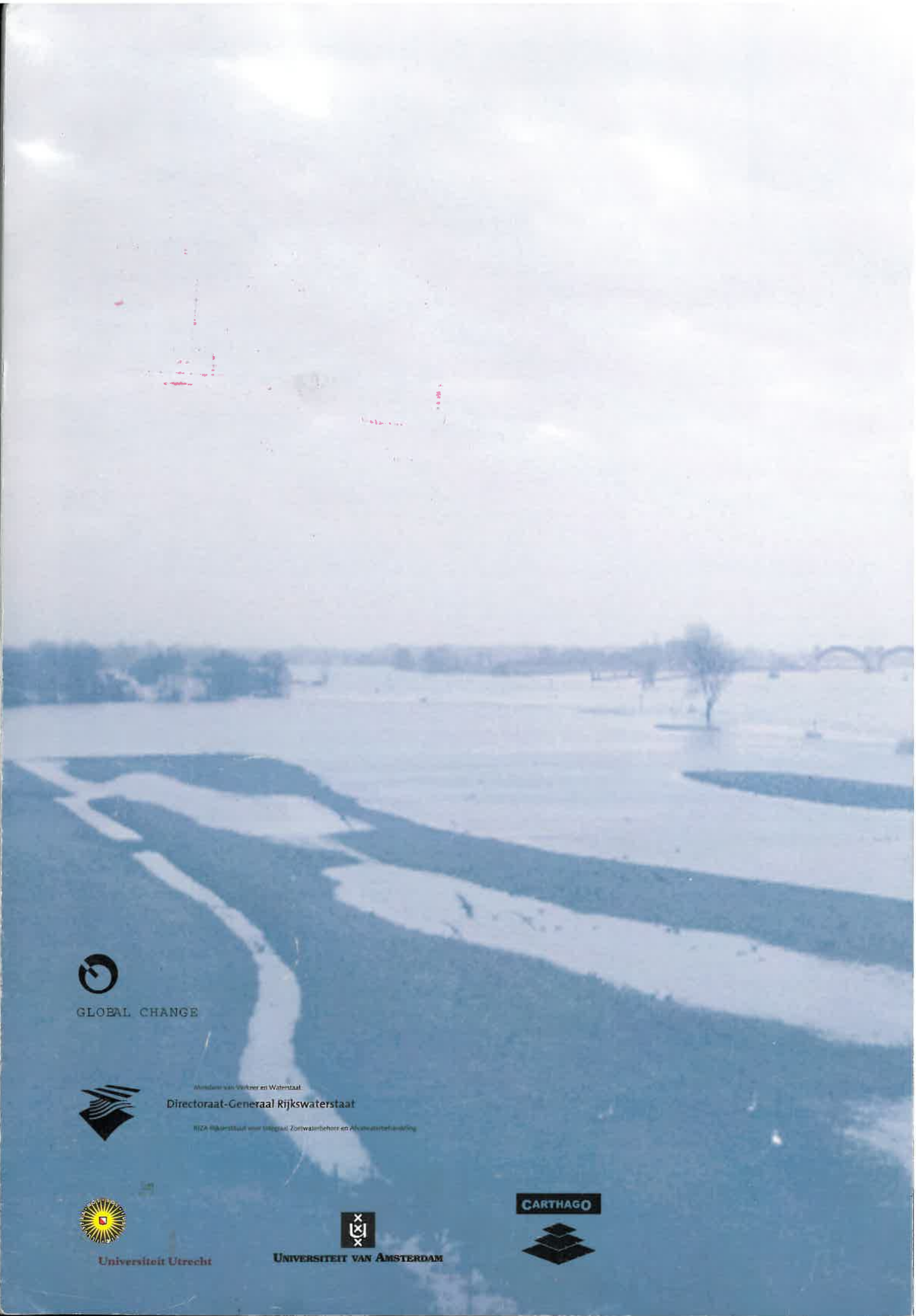

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