Simulation of critical loads for nitrogen for terrestrial plant communities in The Netherlands

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ABSTRACT

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An iterative search procedure was used to 'invert' the soil chemical model SMART2. This 'inverted' form of SMART2 was used to estimate atmospheric nitrogen deposition at the critical conditions for 139 terrestrial vegetation associations. The critical conditions are the lower end of the pH range, and the upper end of the nitrogen availability range for each association, estimated on the basis of Ellenberg values of vegetation relevees. The resulting critical load values were subjected to an uncertainty analysis. The estimation of nitrogen availability on the basis of Ellenberg's indicator for N has the largest contribution to the uncertainty. The critical load over all vegetation types and soil types is estimated to be 22 $\pm$ 8 kg N $ha^{-1}.y^{-1}$. This is a rather 'hard' value, however critical loads per vegetation type are less 'hard', and it is not possible to determine critical load values per site. The uncertainties can only be reduced if more data become available on the abiotic response per species under field conditions. The critical loads found in this study were compared to the 'herijking' and 'SMB' critical loads and to empirically derived values. The 'SMB' critical loads appeared to be far lower than all other critical loads, which were in the same order of magnitude.

Keywords: critical load nitrogen deposition soil vegetation biodiversity

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Preface

The quality of many Dutch ecosystems has declined during the last decades as a result of various, interrelated environmental problems, such as acidification, eutrophication, desiccation, pollution, disturbance and habitat destruction. Drinking water production, wood production and nature conservation, all different ecosystem functions, are threatened. The Ministry of Housing, Spatial Planning and the Environment and the Ministry of Agriculture, Nature management and Fisheries have defined goals for protection of the different ecosystem functions. In this context, the critical load concept was developed and the first critical loads for ecosystems were calculated as early as the mid 1980s.

In an evaluation of the Dutch acid rain abatement strategies (the so-called 'herijking verzuringsdoelstellingen') around 2000, critical loads were computed for the whole of the Netherlands in view of the protection of:

1. Ground water quality, protection against contamination by nitrate (critical N load) and Al (critical acid load);
2. Forests (soils) against nutrient unbalance due to elevated foliar N contents (critical N load) and against root damage due to elevated Al/BC ratios or soil quality deterioration by requiring no changes in pH (or base saturation) and/or readily available Al (critical acid load);
3. Plant species composition in terrestrial ecosystems and moorland pools against eutrophication (critical N load) and acidification (critical acid load).

In this context, the critical loads for the protection of plant species composition in terrestrial ecosystems and moorland pools appeared generally to be the most sensitive ones. This type of critical load was calculated by using an inverse mode of the model SMART2-MOVE. The Multiple stress mOdel for the VEgetation (MOVE) was used to calculate critical limits for nature targets, based on specific information on habitat preferences for nitrogen availability and soil pH for each plant species. The dynamic soil model SMART2 was used to calculate the critical loads above which the critical limits were not exceeded. In cases where no critical loads could be calculated the lowest empirical critical loads from similar ecosystems were applied.

Since critical N loads for nature target types are first of all considered most relevant and also most strict, more information is needed on its accuracy and also the possibility to allow reliable calculations for the various nature target types defined. Consequently, the Dutch Ministry of Agriculture, Nature and Fisheries and the Dutch Ministry of Housing, Spatial Planning and the Environment commissioned Alterra to further investigate the order of magnitude of critical loads for nitrogen for terrestrial plant communities in The Netherlands.

This study used a dynamic soil vegetation modelling approach comparable to SMART-MOVE but focusing on plant associations instead of on individual species.

Furthermore, the reliability (uncertainty) of the estimates was investigated and results were compared with previous estimates by the SMART-MOVE approach, empirical data and a steady-state approach that is generally used by the countries outside the Netherlands when calculating critical N loads.

The main premise of this report is that it gives insight into the reliability of critical load estimates in view of knowledge and data uncertainty, and a comparison of estimates used by various other countries, thus allowing an appreciation of the Dutch critical load input in the international negotiation process in comparison to that of other countries.

Summary

A critical load is 'a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge'. Critical loads play an important role in the setting of emission and deposition standards, and in the protection of natural areas. The present study focuses on critical loads for natural vegetation. There are two methods to determine critical loads for vegetation: empirically, and by simulation. The empirical method uses vegetation and soil 'mesocosms', collected in the field, to which nitrogen or acid are experimentally added. The simulation method uses knowledge of abiotic processes in the soil, and knowledge on the abiotic response per species.

The present study concentrates on simulation to estimate the critical load per vegetation association. The sensitivity of each association to acidity and nitrogen is determined from its mean Ellenberg number for acidity ('R') and nitrogen ('N'), respectively. The critical conditions are assumed to be those encountered at the P_{20} of Ellenberg R (lower end of the pH range) and P_{80} of Ellenberg N (upper end of the nitrogen availability range), determined on the basis of a large set of vegetation relevees. The deposition at these conditions is estimated by an iterative search procedure that uses the model SMART2 to estimate deposition of nitrogen and acidity at given values for soil pH and nitrogen availability. Abiotic conditions that are input to SMART2 are derived from expert knowledge (mostly taken from the descriptions of the association's abiotic preferences). For the soil an overlay procedure of the relevee's co-ordinates and the soil map was also used. To translate Ellenberg values into physical units, a training set of vegetation relevees with known abiotic conditions was used for acidity (R) and water level (F). For nitrogen availability this was not possible, and nitrogen availability was estimated for a training set of historic vegetation records, using the model SMART2 and estimated historic deposition to infer N availability.

The result of this study is a list of simulated critical loads for all terrestrial associations that are included in the Dutch system of 'Nature Target Types'. The average critical load over all vegetation types and soil types is 22 $\pm$ 8 kg N $ha^{-1}.y^{-1}$. The results were subjected to an uncertainty analysis. The uncertainty in the generic critical loads per association is small, however on a site basis the variability is very large. The translation from Ellenberg N to N availability is responsible for a large part of the uncertainty. The results were compared to those of earlier simulation studies (including the one used for the 'herijking vezuringsdoelstellingen' project and the 'SMB' method), and to a recent compilation of empirical critical loads. The SMB method yields critical load values that are far lower than those derived in the present study, but the other methods yield values that are in the same order of magnitude, although the simulated values tend to be slightly higher than the empirical ones. There is no significant correlation between values derived for individual vegetation types by the present method and the SMB or the empirical method.

It is concluded that:

1. the value of the overall critical load for the Netherlands is rather 'hard' because the uncertainty in the simulated value is low, and this value is in agreement with the value from other simulation and empirical studies;
2. the critical load values per vegetation type are less 'hard'; although the uncertainty in the simulated values is low, there is no correlation between the empirical and simulated values per type, even though their ranges usually overlap;
3. it is not possible to determine critical loads per site because in that case the uncertainty in the simulated values becomes extremely high;
4. field data on the response of species to abiotic conditions are required to decrease the uncertainty in the simulated critical loads.

1 Introduction

A critical load is 'a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge'. In this context, 'significant harmful effects' may be (a) chemical changes in soils and waters which might cause direct or indirect effects on organisms, or (b) changes in individual organisms, populations or ecosystems (Nilsson & Grennfelt 1988). Critical loads have an important role in policy, e.g. in the planning of nature targets, in agricultural restructuring, in the setting of emission standards and deposition targets, and in the implementation of the European 'Habitat Directive'. The present study focuses on critical loads for natural vegetation. Critical loads for nitrogen can be estimated empirically or by simulation. The former method uses experimental fields or 'mesocosms' where various levels of nitrogen fertiliser have been added. In that case, the critical load is determined as the level of deposition where a decrease in biodiversity just starts to occur (Achermann & Bobbink 2003). The latter method relies on model calculations to estimate the deposition levels leading to soil conditions that are just tolerated by a given ecosystem. In that case the model itself follows a well-described mathematical procedure, but its input consists of either field observations, or expert knowledge that is subject to a certain amount of uncertainty. Therefore the critical loads derived by both methods have some uncertainty; in the empirical method the uncertainty is mostly due to the generalisation of experimental conditions to field conditions, whereas in the simulation method most uncertainty is caused by a lack of data on the abiotic responses per species. The differences between the two methods are summarised in Table 1. In both methods validation can be carried out against field observations on natural vegetation at various levels of deposition.

Table 1: summary of differences and similarities between empirical and simulated critical loads

	empirical critical load	modelled critical load
reference situation	vegetation at unpolluted 'reference' sites, or historic records	
criterion for loss of biodiversity	loss of species	
relation deposition <=> biodiversity	from field or mesocosm studies	from soil processes and abiotic response per species
source of data	experimental or (sometimes) observational	species responses: observational or expert knowledge soil: process knowledge
vegetation typology	few, broadly defined types	many, narrowly defined types
major sources of uncertainty	generalisation of experiment to field	uncertainty in abiotic response per species
	lack of data on abiotic conditions in field sites	

Critical nitrogen loads for The Netherlands related to the species diversity of terrestrial ecosystems have been estimated by simulation on two earlier occasions.

The study by van Hinsberg & Kros (1999) used a regression-based procedure to 'invert' the model chain SMART2-MOVE (Kros 2002, Latour et al. 1994) to produce a relationship between deposition and 'protection level' per Nature Target Type (Bal et al. 1995). This study used a species-based approach, and for each target type the 'protection level' was determined as the percentage of species belonging to that type that is expected to occur at a given level of deposition. The critical loads were derived on the basis of a 90% protection level. In contrast, the study by Schouwenberg et al. (2000a, unpublished) used a community-based approach. Here too, an 'inverted' form of the SMART2 model was used, but the abiotic requirements per vegetation type (association) derived from mean Ellenberg numbers were used as input. The critical conditions were assumed to be those that exist at the lower end of the pH range and the upper end of the N availability range of each association. Both methods yielded comparable, but not identical, results. Also, the simulated and empirical critical loads are in the same order of magnitude, although not identical.

In a recent evaluation of pollution abatement policy in The Netherlands, Albers et al. (2001) compared several criteria to determine critical loads: vegetation changes, increase in stress sensitivity (e.g. to frost and diseases) of trees, nutrient imbalance (especially the K/NH_4 ratio in soil water), and nitrate leaching to the groundwater. Of all these criteria, vegetation change appeared to be the most sensitive one (i.e., the one yielding the lowest critical load values). Therefore, the critical loads based on ecological criteria, and their uncertainties, are of the utmost importance for emission reduction policy.

The present study has three aims: (1) to critically re-evaluate the results of Schouwenberg et al. (2000a), using an improved procedure for the 'inversion' of the SMART2 model, and based on more field data to estimate the abiotic response per species or per vegetation type; (2) to determine the uncertainty in the critical load estimated by the above method, and (3) to make a comparison between both the empirical method, and the simulation methods by van Hinsberg & Kros (1999), Schouwenberg et al. (2000a), and its present improvements. This comparison should ultimately lead to a 'best available judgement' of the critical load for each nature target type, that can be used for environmental policy. The uncertainty should be explicitely included in this judgement, ultimately leading to an overview of additional work to be done in order to reduce uncertainties. It should be stressed, however, that the production itself of a 'best available judgement' is outside the scope of the present study, which solely focuses on the simulation of critical loads for nitrogen, and the uncertainty in its results.

2 Material and methods

2.1 General approach

Normally, the model SMART2 is used to estimate the soil conditions that determine biodiversity (pH and nitrogen availability) at given deposition levels of sulphur and nitrogen compounds (Kros 2002). In the present application, SMART2 is 'inverted' to produce deposition levels that will ultimately lead to a given pH and N availability. For this purpose an iterative procedure was developed that in successive SMART2 runs with varying deposition levels, searches the deposition levels that most closely approximate predefined ('requested') values for soil pH and N availability. The values for soil pH, N availability and deposition that result from this iterative search procedure are termed the 'optimised' values. Besides deposition, SMART2 uses soil type, vegetation type and hydrology (as Mean Phreatic Level in Spring [MPLS], seepage quantity and seepage quality) as inputs. In the iterative inversion procedure these variables were used as constant inputs.

As the present study aimed at deriving a critical load for each vegetation type, the input variables for $SMART2^{-1}$ had to be estimated per vegetation type. As vegetation types, the associations in the sense of Braun-Blanquet (1964) were used, as described for The Netherlands by Schaminee et al. (1995a, 1995b, 1996, 1998), and Stortelder et al. (1999) (further referred to as 'Schaminee et al. 1995'). A selection was made of the vegetation database built by Schaminee et al., consisting of those associations (and a few sub-associations) that belong to Nature Target Types (in the sense of Bal et al. 1995); this selection is identical to the one used by Wamelink et al. (2001). Details of the selection procedure are given in section 2.2.1. For each of these associations the $SMART2^{-1}$ input variables were estimated at abiotic conditions where this association is just able to survive without a significant loss of biodiversity (i.e., at the conditions that exist at the critical load). The methods used to derive values for the relevant abiotic conditions are summarised in Table 2. Details for each abiotic variable are given in Sections 2.2.1. The whole procedure to derive the critical loads is summarised in Figure 1. The $SMART2^{-1}$ procedure was subjected to a sensitivity analysis, and the derived critical loads were subjected to an uncertainty analysis. These analyses are described in Section 2.3.

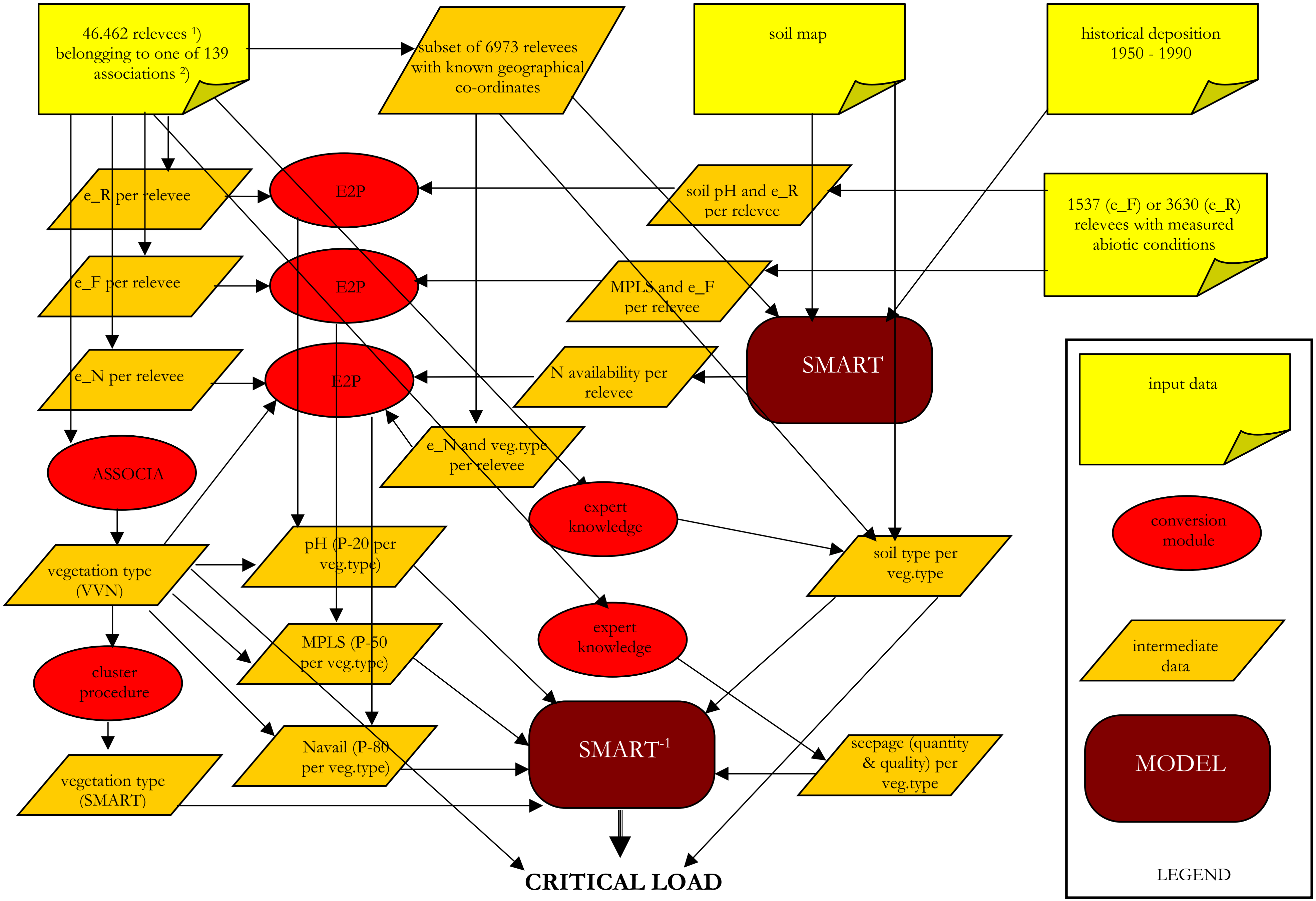

Figure 1 (next page): schematic representation of method used to derive critical loads by simulation. e_F, e_R, e_N = Ellenberg numbers for humidity, pH and N availability, respectively; MPLS = mean phreatic level in spring; P-XX = XX-percentile; E2P = regression equation to convert Ellenberg units to physical units; VVN = in the sense of Schaminee et al. (1995). [1]) relevees taken from Schaminee et al. (1995). [2]) associations used to define 'Nature Target Types' by Bal et al. (1995).

Table 2: source of input variables for SMART2^{-1}. All variables are determined per combination of association and soil type.

variable	source	training set for translation function
soil pH	P_{20} of soil pH of relevees, estimated on the basis of average e_R per relevee	relevees with measured pH
MPLS	P_{50} of MPLS of relevees, estimated on the basis of average e_F per relevee	relevees with measured MPLS
N availability	P_{80} of N availability of relevees, estimated on the basis of average e_N per relevee	relevees with known co-ordinates, and historic N availability estimated by SMART2
vegetation type [1])	association	floristic composition of association
soil type [2])	association or: soil type per relevee	expert knowledge relevees with known co-ordinates, and soil map
seepage quantity	association	expert knowledge + fine-tuning of optimised pH
seepage quality [3])	association	expert knowledge
SO_x deposition	expected value for 2010	constant at 0.4 kMol.ha^{-1}.y^{-1}
NH_y / NO_x deposition	present-day value	constant at 2.56

[1]) as SMART2 types: coniferous forest, deciduous forest, heathland, grassland
[2]) as SMART2 types: sand poor, sand rich, sand calcareous, clay non-calcareous, clay calcareous, loss, peat
[3]) in six classes: rain water, surface water, mixed water, ground water, brackish water, sea water

2.2 Details of the calculation procedure

SMART2 was used to determine the maximum deposition values for NH_3, NO_x and SO_2 above which the critical limits for pH and nitrogen availability are exceeded. In the earlier studies by van Hinsberg & Kros (1999) and Schouwenberg et al. (2000a) this was done by regressing SMART2's output on its input, based on a large set of model simulations representing different abiotic conditions. In the present study, however, SMART2 was embedded in an optimisation procedure, using a controlled random search (CRS; Price 1979) for global optimisation. For each considered vegetation type this optimisation was used to derive the nitrogen deposition yielding the minimum pH and maximum nitrogen availability corresponding to its critical conditions. In order to find a unique solution for each vegetation type, additional constraints had to be provided for the SO_2 deposition and the NH_3 to NO_x ratio. For the SO_2 deposition the national average value expected for 2010, i.e. 400 mol$_c$.ha^{-1}.y^{-1} was used, and for the NH_3 to NO_x deposition ratio the present-day value of 2.56 (Anonymous 2002). The critical conditions for each vegetation type were determined on the basis of vegetation relevees and their estimated abiotic conditions, according to the procedures given below.

2.2.1 Selection of vegetation relevees

As a starting point a selection was used of the Dutch National Vegetation Database (Hennekens, pers. comm.; cf. Schaminee et al. 1995). This selection, consisting of

160,209 relevees, is assumed to give a balanced overview of the vegetation of The Netherlands (Runhaar et al. 2002). The same selection was used for the calibration procedure of NTM (Schouwenberg 2002, Wamelink et al. 2003), and for the earlier estimation of critical loads by Schouwenberg et al. (2000a). The relevees in this selection were assigned to vegetation types in the sense of Braun-Blanquet (1964) using an automated procedure. This procedure ('supervised classification') was carried out by the program ASSOCIA (van Tongeren in prep.) which is shortly described by Wamelink et al. (2003). Next, a subset was made of this selection, containing those relevees that belong to the 139 vegetation types that occur in the list of Wamelink et al. (2001) (i.e., the ones that were used for the definition of the 'Nature Target Types' by Bal et al. 1995). In making this subset the relevees that were assigned to subassociations by ASSOCIA were assigned to the corresponding associations, except for the subassociations that occur in the list by Wamelink et al. (2001), which were kept as such. Relevees that ASSOCIA assigned to vegetation types above the level of association were not included. This resulted in a subset containing 46,462 relevees.

2.2.2 Determination of the abiotic conditions at the critical load

For most of the relevees in the selection described above the abiotic conditions are unknown. Therefore, these abiotic conditions had to be estimated from the species composition of the relevees, their geographical location combined with generic data, or expert knowledge on each association's abiotic preference. The vegetation type related abiotic conditions used as input to $SMART2^{-1}$ are soil type, soil pH, N availability, and hydrology. The hydrological conditions are characterised by three indicators: the Mean Phreatic Level in Spring (MPLS, in cm below soil surface), the seepage (i.e. the upward groundwater movement, in $mm.day^{-1}$), and the seepage quality (i.e. the ionic composition of the seepage water, in a number of classes). Moreover, $SMART2^{-1}$ uses a simple typology of vegetation structure and soil type. The model was applied by using generic vegetation structure and soil type related parameters. For precipitation and deposition of base cations average values for The Netherlands were used.

The procedures used to estimate the abiotic conditions are summarised in Table 2. Soil pH, MPLS and N availability were estimated per relevee on the basis of Ellenberg numbers. For soil type a hybrid procedure was used based on both expert knowledge (taken from the association's descriptions in Schaminee et al. 1995), and an overlay of the soil map and each relevee's co-ordinates (section 2.2.3). Quality and quantity of seepage were estimated on the basis of expert knowledge, again based on the association's descriptions in Schaminee et al. (1995). The SMART2 vegetation structure types were directly assigned to the associations on the basis of their floristic composition.

Out of the abiotic conditions that are input to $SMART2^{-1}$, pH and N availability are influenced by deposition. Changes in these conditions are the direct cause of the disappearance (or loss of diversity) of certain vegetation types at increasing deposition. These losses are caused by either a too low pH value ('acidification'), or a too high N availability ('eutrophication'). Therefore, the pH value at the critical load was estimated as the lower end of the pH range of each association. In the present study this lower end was defined as the 20-percentile (P_{20}) of the pH values of the relevees belonging to a given association. Similarly, the N availability at the critical load was estimated as the higher end of the N availability range of each association, for which the 80-percentile (P_{80}) of the N availabilities in a given association was taken. MPLS is not influenced by deposition, and therefore its value should represent average conditions per association rather than the conditions at the critical load. Therefore, the MPLS per association was defined as the 50-percentile (P_{50}) of the values of its constituent relevees.

The abiotic conditions for pH, MPLS and N availability were estimated for each relevee on the basis of its mean value of the corresponding Ellenberg numbers (R, F and N, respectively). The Ellenberg values per relevee were calculated as unweighted means over all species (including mosses and lichens), without a minimum for the number of species per relevee. As input, the tables by Ellenberg (1991), Düll (1991) and Wirth (1991) were used, except for the N values for mosses which were taken from Siebel (1993). As SMART2^{-1} uses pH, MPLS and N availability expressed in physical units as its input, translation functions are required to convert Ellenberg numbers into physical units. These translation functions are the reverse of the translation functions used by e.g. Liefveld et al. (1998) or Schouwenberg et al. (2000b), where physical units were converted into Ellenberg numbers (cf. Wamelink & van Dobben 2003). The submodel that is responsible for the translation of Ellenberg values into physical values is referred to as 'E2P'. Its parameterisation is described in 2.2.5 and 2.2.6.

2.2.3 Determination of soil type per association

The soil type was determined by two methods: expert knowledge, and overlaying the co-ordinates per relevee and the soil map. The expert knowledge comes from Schaminee et al. (1995) and is simply the soil type that is mentioned in the description of each (sub)association. This assignment of soil type to vegetation type is equal to the one used in the earlier study by Schouwenberg et al. (2000a). For the overlay procedure the soil map was simplified to the SMART2 typology (Kros 2002; Table 3), and a contingency table of soil types and vegetation types was made (7 soil types, 139 vegetation types, 6973 relevees with known co-ordinates). For each vegetation type the number of relevees per soil type was determined, and if >30% of the total number of relevees was on a given soil type, that soil type was assigned to the vegetation type. As a result of this procedure the number of soil types per vegetation type varies between zero and three.

Table 3: soil types used in SMART2

soil	code
sand poor	SP
sand rich	SR
sand calcareous	SC
clay non-calcareous	CN
clay calcareous	CC
loess non-calcareous	LN
peat non-calcareous	PN

There is considerable uncertainty in the result of the overlay procedure because of the inaccuracy and generalisation in the soil map, which has a scale of 1:50 000 (Steur and Heijnink 1991). This is especially true because vegetation relevees are usually not randomly located, and may represent rather isolated spots with specific abiotic conditions. Therefore the resulting table was scanned by a group of experts, and combinations of vegetation and soil that were considered highly improbable were manually removed. Subsequently, the soil types derived by expert knowledge and those derived by overlaying were combined into a single table, which is displayed in Appendix 1. As a result of this procedure, more than one critical load may be derived for each vegetation type, depending on the soil types on which it occurs. Therefore the number of critical loads that is finally estimated (228) exceeds the number of associations included in this study (139).

2.2.4 Determination of vegetation type (in the sense of SMART2)

As the vegetation typology used in SMART2 is very simple (Table 4) and the typology on the level of (sub)association is quite detailed, the (sub)associations can be simply clustered into SMART2 types on the basis of their floristic composition. The SMART2 types are pine forest, spruce forest, deciduous forest, heathland and nutrient-poor grassland. However, 'spruce forest' is not used in this study as this vegetation type does not naturally occur in The Netherlands. The assignment of the other two forest types, and the 'heathland' type are quite straightforward, and all remaining vegetation types are considered as 'grassland'. The result can be seen in Appendix 1.

Table 4: vegetation types used in SMART2.

vegetation	code
deciduous forest	DEC
pine forest	PIN
spruce forest [1])	SPR
heathland	HEA
nutrient-poor grassland	GRP

[1]) For the present application the 'spruce forest' type is not used because it does not naturally occur in the Netherlands.

2.2.5 Estimation of pH and MPLS from Ellenberg numbers

For both pH and MPLS, relevees with known values of these variables were collected and used as a training set. These relevees are from various sources, described by Sanders et al. (2000) and Wamelink et al. (2002). The relation between Ellenberg's R (e_R) and pH, and between Ellenberg's F (e_F) and MPLS, respectively, was determined by simple linear regression. As Wamelink et al. (2002) showed that translation functions may be different per vegetation type, the type was included as an extra explanatory variable. However, the effect of type appeared to be nonsignificant in this case, which may be due to the course typology used here (namely, as the five 'SMART2 types'; see Table 4). Details of the regression analyses are given in Table 5. The regression equations resulting from this analysis were used to transform e_R and e_F into pH and MPLS, respectively. However, as e_R is only weakly related to pH in calcareous soil (Schaffers & Sykora 2000), the pH was set to 7 on calcareous soil types, irrespective of the value e_R.

Table 5: regression of MPLS and soil pH on e_F and e_R. Model tested: MPLS or pH = $a_0 + a_1$(e_X)

variable	N records	perc expl var	a_0			a_1		
			mean	±	se	mean	±	se
e_F	1537	22%	235.64	±	7.08	-21.57	±	1.02
e_R	3630	43%	3.1065	±	0.0512	0.52663	±	0.8395

2.2.6 Estimation of N availability from Ellenberg N

The procedure used to derive translation functions for e_R and e_F cannot be used for Ellenberg's N (e_N) because measurements of N availability are not available on a sufficient scale. Therefore N availability was estimated per relevee using generic data and the relevee's geographical co-ordinates. These generic data were the historic deposition levels of SO_x, NO_x and NH_y in 1950, 1960, 1970, 1980 and 1990, the soil type, and the seepage quantity and quality per 250 X 250 m^2 grid cell. Deposition values for the period 1980-1990 were available at a 5 × 5 km^2 grid and based on emission-deposition calculations, whereas the values for 1950-1970 were scaled by using generic emission scaling factors (Eerens & van Dam 2000). A selection was made of the input dataset of 160,209 relevees, containing the relevees in the list of Wamelink et al. (2001) that had known geographical co-ordinates and a value for e_N. This selection contained 6911 relevees. The model SMART2 (Kros 2002) was used to estimate the N availability in the grid squares where each of these relevees were located, as the sum of deposition and mineralisation at the points in time mentioned above. As nearly all relevees were made during the period 1945 - 1995, the average of the modelled N availabilities at the five points in time mentioned above were assumed to represent the actual N availability for the relevees.

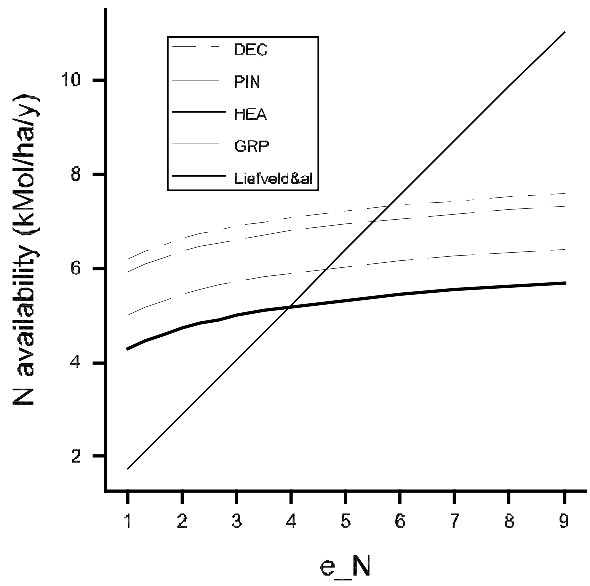

Figure 2: regression lines for the conversion of Ellenberg's N (e_N) into N availability in kMol.ha^{-1}.y^{-1}. Lines are given per vegetation type (DEC = deciduous forest, PIN = coniferous forest, HEA = heathland, GRP = grassland) derived from the regression equation specified in Table 4. As a comparison the regression line derived by Liefveld et al. (1998) is also given.

The N availability estimated above was regressed on the mean Ellenberg N per relevee, using the vegetation type as an extra explanatory factor. In contrast to the regression analyses for pH and MPLS, the effect of vegetation type was highly significant (see Table 6 for details). Both linear, quadratic and logarithmic translation functions were tested. The logarithmic one was finally chosen, because the three functions yielded nearly equal percentages explained variance, but (1) a linear function yields very high (and probably unrealistic) N availabilities at high e_N values, and (2) a quadratic function causes the N availability to decrease at the higher end of the e_N scale. Figure 2 gives the translation functions as used in the present study, compared to the one derived by Liefveld et al. (1998). The latter one was mainly derived from expert judgement, and was also used by Wamelink et al. (1997), Schouwenberg et al. (2000a, b), van Dobben et al. (2001), and Schouwenberg (2002). In the translation function presently used the N availability is much less sensitive to e_N than in the one used in the earlier studies. The study by van Hinsberg & Kros (1999) used yet another translation function, derived by Ertsen (1996).

Table 6: regression of N availability on logarithmised Ellenberg N and vegetation types (according to SMART2 classification). Regression equation:
*N availability (in kMol.ha^{-1}.y^{-1}) = $a_0 + a_1 log(e\_N) + c_{vegtype}$. The constants per vegetation type are relative to deciduous forest, and therefore $c_{deciduous} = 0$. Percentage explained variance = 24%, number of records = 6911, significance: *** = P<0.001, * = 0.01<P<0.05.*

variable	symbol	estimate		s.e. significance
intercept	a_0	6.191	±	0.106***
log(e_N)	a_1	0.6367	±	0.0608***
vegetation types:				
grass	c_{grass}	-1.1817	±	0.0394***
heath	c_{heath}	-1.8983	±	0.0842***
coniferous	$c_{coniferous}$	-0.274	±	0.123*

2.2.7 Determination of seepage quantity and quality

First it was attempted to estimate both MPLS and seepage quantity and quality by an overlay procedure similar to the one used for the soil types. However, as the uncertainty in the hydrological maps (groundwater stage map, included in the soil map of the Netherlands, Steur & Heijnink 1991; and seepage map, based on model calculations, Beugelink in prep.) is even larger than in the soil map, it was decided to derive MPLS from Ellenberg numbers, and to rely entirely on expert knowledge for seepage. In SMART2, seepage is an external source of ions. Therefore, seepage was used in a rather broad sense, not only accounting for the upward movement of groundwater but also for the influence of surface water. The position of each vegetation type relative to groundwater or surface water was taken from Schaminee et al. (1995), and translated into a hypothetical seepage quantity. Classes for 'seepage' quality (also reflecting surface water quality) were assigned on the basis of Schaminee et al. (1995) and Table 7. As the assumed seepage quantity has a strong influence on the pH, the seepage quantities in Table 8 were determined by fine-tuning, so that the optimised pH approximated the requested pH as closely as possible. Especially at low seepage quantities the optimised pH was extremely sensitive to the seepage (Table 9). For the determination of the critical loads the seepage quantity in the lowest nonzero class (periodically flooded etc.) was set to 0.15 mm.day^{-1} because this values yielded the best approximation of the requested pH (Table 9). For the most strongly seepage-dependant vegetation type (Pellio epiphyllae-Chrysosplenietum oppositifolii) it was not possible to tune seepage such that the optimised pH and the requested pH differed by less than one unit, and for this vegetation type no critical load was determined. The seepage quantities and qualities per association as determined by the above procedures are given in Appendix 1.

Table 7: seepage quality classes

origin of water	class number
rainwater	0
mixed water	1
groundwater	2
brackish water	3
seawater	4
surfacewater [1])	5

[1]) the composition of surface water is assumed to be equal to the composition of the water of the Rhine at the Dutch - German border.

Table 8: assignment of hypothetical seepage quantity values to vegetation types

groundwater or surface water influence	hypothetical seepage (mm/day)
no water influence	0
periodically flooded, fen, bog hummocks	0.15
shore vegetation, partly immersed, bog gullies	1
immersed but temporarily dry	2
permanently immersed	3
'real' seepage-dependant vegetation [1])	5

[1]) used for only one vegetation type (Pellio epiphyllae-Chrysosplenietum oppositifolii)

Table 9: mean and standard deviation of difference in pH (requested - optimised) for the seepage classes defined in Table 8.

Seepage	mean	±	s.e.	N
0	0.45	±	0.60	81
0.15	-0.09	±	1.00	35
1	0.07	±	0.51	80
2	0.10	±	0.55	25
3	0.08	±	0.50	6
5	-1.93	±	*	1 [1])
overall	**0.18**	**±**	**0.68**	**228**

[1]) not used for the determination of critical load.

2.3 Sensitivity and uncertainty analysis

Sensitivity analysis can be accomplished by regressing the output of a model on its input. It will tell which of the input variables most strongly influence the output of the model, given the range and mutual correlations of the used input data. Uncertainty analysis is also accomplished by regressing model output on model input, however not using the original input data, but a range of possible realisations of the input data. These realisations are generated artificially, taking account of the statistical distribution of each input variable.

The uncertainty analysis applied in this study is of the Monte Carlo type, which means that the uncertainty in the output is determined on the basis of a random sample from the possible inputs. For this purpose 100 samples of possible (physical) abiotic values were drawn for each combination of association and soil type, based on their mean Ellenberg values and the translation functions for all three abiotic variables, and the uncertainty of, and correlation between, the parameters of these translation functions (total 100x228=22,800 records). All other inputs to the model (e.g. seepage) were considered constant, and the model was run for each of these records. The contribution of each of the inspected parameters to model uncertainty was estimated by regression. The rationale behind this method is given below.

2.3.1 Sources of error

Prediction errors in model studies arise in several ways, in particular by (i) exogenous variables that do not develop as assumed; (ii) errors in initial values; (iii) errors in parameter values; and (iv) errors or simplifications in the model structure.

Exogenous variables
Errors in exogenous variables (e.g. precipitation) are most important in studies where the effect of such variables on target variables (e.g. soil pH or vegetation structure) is stimulated. However, in the present study the aim is the reverse, namely the estimation of exogenous variables (deposition) at given values of the target variables (pH, N availability). Therefore this type of error does not play a role here.

Errors in initial values
Errors in initial values are most important in scenario studies where changes over time are being simulated. As this is not the case here, such errors were left out of consideration. In the present case the initial values are chosen randomly, and deposition is varied until the requested pH and N availability are realised. However, it cannot be excluded that in some cases there is no unique solution, i.e. the requested pH and N availability are realised at more than one deposition value. In such cases the initial values given to the optimisation procedure may be important, and some attention will be given to this phenomenon.

Errors in parameter values
Errors in parameter values may occur at two points in the present simulation: in SMART2^{-1} and in E2P. Those occurring in SMART2^{-1} will not be considered here, because they are probably of minor importance compared to those in E2P (Schouwenberg et al. 2000b). An example of how to account for errors in SMART2's parameters is described by Kros et al. (1999). The technical side of the evaluation of model uncertainty due to errors in parameter values is discussed by van Dobben et al. (2002). In the present study, the parameter values of E2P were estimated by regression analyses. These analyses provide standard errors and correlations of estimates, which were used in the subsequent analysis. However, in regression analysis two sources of uncertainty can be distinguished: the uncertainty in the regression coefficients, and the variation in the data that is not explained by the regression equation. This latter variation will be called unexplained system variation (USV). The errors due to this source of variation were also quantified and incorporated in the uncertainty analysis.

Errors or simplifications in the model structure
Most often, in an uncertainty analysis, model structural errors remain out of sight: in absence of counter-evidence, it is assumed that the model structure is correct, and the analysis only studies how input uncertainty propagates through the model as it is. An obvious type of structural error is the omission of a process that has little effect on a small time-scale, but gains importance on larger time-scales. Such a process can easily be overseen when the model is parameterised and tested using data collected over a short period of time, but it may cause sizeable prediction error in a long-term model study. In the present study some attention is given to the uncertainties and errors due to the chosen model structure. However, no attempts have been made to quantify these errors.

Parametric uncertainty and unexplained system variation
The notion of unexplained system variation was already discussed by Schouwenberg et al. (2000b). An example is the measurement of soil pH in a given vegetation type. The variation in measured values is due to two sources of error: measurement errors, and the intrinsic variation in soil pH in the considered vegetation type. The effects of the measurement errors can be minimised by increasing the number of measurements, and, in the case of regression, its magnitude is reflected in the standard errors of the regression coefficients. However, the intrinsic variation is independent of the number of observations, and, in regression, is reflected by the residual mean square (RMS).

The concept of unexplained system variation is implicitly present in the well-known calculation of confidence bounds around a regression line, discussed in many statistics textbooks (e.g. Draper & Smith 1998, p. 80-83; or Oude Voshaar 1994, p. 69). The point made in these books is that there is a difference between the uncertainty about the expected value of a new observation, and the uncertainty about a single new observation, but the textbooks do not make a distinction between measurement errors and unexplained system variation.

2.3.2 Overview of inspected sources of variation

In order to restrict the number of Monte Carlo simulations it was attempted to limit the number of inspected input data. The limitation was based on the sensitivity analysis, and on expert judgement on the uncertainty of the parameters. All rather certain and rather insensitive parameters were left out. Finally, only the parameters of E2P were inspected, resulting in nine parameters and three terms for the USV (Table 10).

In the present application, E2P consist of three equations:

$$MPLS = a\_mpls + b\_mpls * e\_F + \varepsilon\_mpls \quad (1)$$

$$pH = a\_ph + b\_ph * e\_R + \varepsilon\_pH \quad (2)$$

$$Nav = a\_nav + b\_nav * \log(e\_N) + \varepsilon\_nav \quad (3)$$

with:
a_x: constant (a_nav has a different value per vegetation type)
b_x: regression coefficient
e_X: Ellenberg value
ε_x: random error

Table 10: mean values and standard errors of E2P parameters [equations (1) - (3)] inspected in the uncertainty analysis

parameter	mean	s.e.
a_mpls	235.64	7.08
b_mpls	-21.57	1.02
ε_mpls	0	45.95
a_ph	3.1065	0.0512
b_ph	0.52663	0.00998
ε_ph	0	0.8395
a_nav (dec)	6.191	0.106
a_nav (grp)	5.0091	0.0932
a_nav (hea)	4.2924	0.0721
a_nav (pin)	5.916	0.133
b_nav	0.6367	0.0608
ε_nav	0	1.4174

The mean values of these parameters and their standard error are given in Table 10; their mutual correlations are given in Table 11. The estimates of the regression coefficients, their variances and correlations describe the *parametric uncertainty* of E2P. The residual mean square of the regressions (reflected in the s.e.'s of the ε's) is caused by measurement errors and *system variability unexplained by the regression*. Assuming that the measurement error is by far the smaller of the two, the residual mean square was used to calculate the variance of the unexplained system variation (USV). The uncertainty analysis was carried out with and without USV to give an idea of the influence of the USV on the uncertainty of the predicted critical loads.

Table 11: correlation coefficients of E2P parameters [equations (1) - (3)] inspected in the uncertainty analysis (the ε's are not given because they are uncorrelated to all other parameters)

	a_mpls	b_mpls	a_ph	b_ph	a_nav (dec)	a_nav (grp)	a_nav (hea)	a_nav (pin)
b_mpls	0.9862							
a_ph	0	0						
b_ph	0	0	-0.9623					
a_nav (dec)	0	0	0	0				
a_nav (grp)	0	0	0	0	0.9307			
a_nav (hea)	0	0	0	0	0.6151	0.6210		
a_nav (pin)	0	0	0	0	0.4919	0.4966	0.3282	
b_nav	0	0	0	0	-0.9601	-0.9694	-0.6406	-0.5123

2.3.3 Technical details

Saltelli et al. (2000) and Jansen et al. (2003) give a detailed account of uncertainty analysis. The principle of the present uncertainty analysis is explained by van Dobben et al. (2002). It was carried out by a number of procedures within the statistical program GENSTSAT (Payne & Ainsley 2000; Goedhart and Thissen 2002). First the procedure GUNITCUBE was used to generate new input for the SMART2^{-1}. This procedure generates pseudo-random numbers from a multivariate distribution with marginal distributions that are uniform on the interval from 0 to 1, and with a given rank-correlation matrix (RCORRELATION). For each combination of vegetation type and soil type 100 samples were drawn. The E2P parameters were assumed to be normally distributed. The method to construct a latin hypercube sample stems from McKay et al. (1979). The method to introduce the required rank correlation stems from Iman & Conover (1982).

The above procedure was applied twice: once to determine the parametric uncertainty, and once to determine the sum of parametric uncertainty and USV. Thus, the model was run 201 times for each combination of vegetation type and soil type: once with mean parameters values as input, 100 times with a sample of parameter values drawn from a distribution taking account of the parametric uncertainty, and 100 times with a sample of parameter values drawn from a distribution taking account of both the parametric uncertainty and the USV.

The contribution of the various model inputs to the uncertainty in terms of the variance of the critical loads per combination of vegetation and soil type was estimated with a generalised additive regression model using a spline function (de Boor 1978). To calculate these contributions the GENSTAT-procedure RUNCERTAINTY was used. This procedure performs uncertainty analysis given (1) a sample of model inputs from a joint distribution representing the uncertainty about these inputs and (2) a corresponding sample of the model output studied. The procedure calculates the contributions to the variance of the model output from individual or pooled model inputs by means of regression. These contributions are expressed as percentages of the variance of the model output. The top marginal variance of a model input is the percentage of variance accounted for when that input term is the only one to be fitted; it is an approximation of the correlation ratio. The bottom marginal variance of a model input is calculated as the decrease of variance accounted for when that input term is dropped from the full model containing all input terms. The calculation is successful if the percentage of variance accounted for by all inputs is close to 100, lower percentages may indicate a strong interaction between input terms. In the present study interaction was not considered.

3 Results

3.1 Performance of the optimisation procedure

The data that were used as input to SMART2-1 are shown in Appendix 1. Figures 3 and 4 give an impression of the performance of the optimisation procedure used to invert the SMART2 model. For both pH and N availability, the optimised value is close to the requested value for most of the records. Especially for N availability the correspondence is close for most records (r=0.91), although on poor sand the optimised N availability sometimes remains considerably below the requested value. The records where this happens correspond to the vegetation types heathland and pine forest. For pH the correspondence between the requested and the optimised value is almost as close as for N availability (r=0.89), but there is a larger number of records with a considerable discrepancy (Figures 4 and 5). These discrepancies occur in all soil types except on clay and on the calcareous types; and also for all vegetation types, although mostly in grassland.

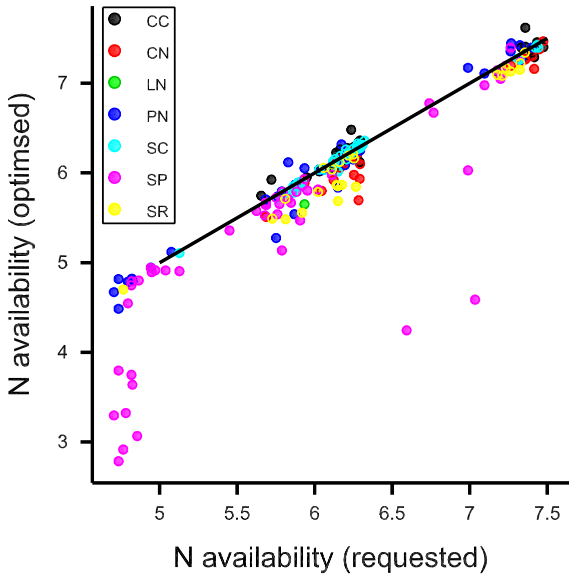

Figure 3: scattergram of requested vs. optimised N availability (in kMol.ha^{-1}.y^{-1}). Drawn line is 1:1. Colours indicate soil types, explanation of soil coding in Table 3.

3.2 Critical loads

The critical loads per vegetation - soil combination resulting from the optimisation procedure are given in Appendix 2. These critical load are derived by adding the optimised deposition values for NO_x and NH_y expressed in kg N.ha^{-1}.y^{-1} [*]. The critical loads are summarised in Table 12. Figure 6 gives an impression of the relation between critical load, vegetation type and the requested N availability (i.e., the P_{80} of the estimated N availabilities per relevee of each association). Although the critical load is to a certain extent dependent upon the requested N availability, it also appears to be strongly influenced by the vegetation type. Figure 7 is identical to Figure 6 but with the vegetation type indicator replaced by an indication of the discrepancy between the requested and the optimised pH. There appears to be no consistent relation between the critical load and the deviation of the optimised pH from the requested value.

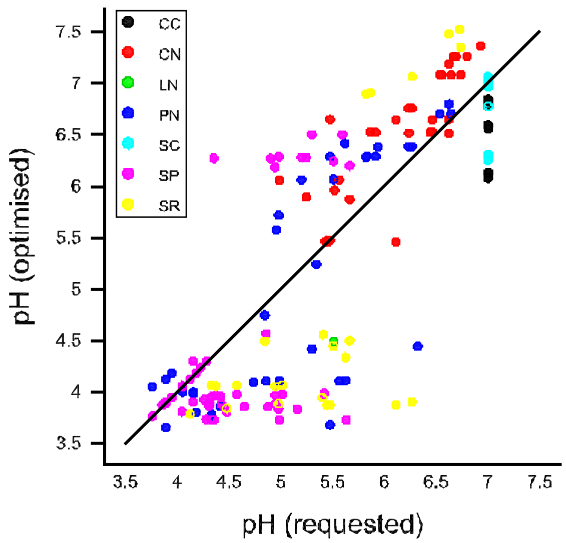

Figure 4: scattergram of requested vs. optimised pH. Drawn line is 1:1. Colours indicate soil types, explanation of soil coding in Table 3

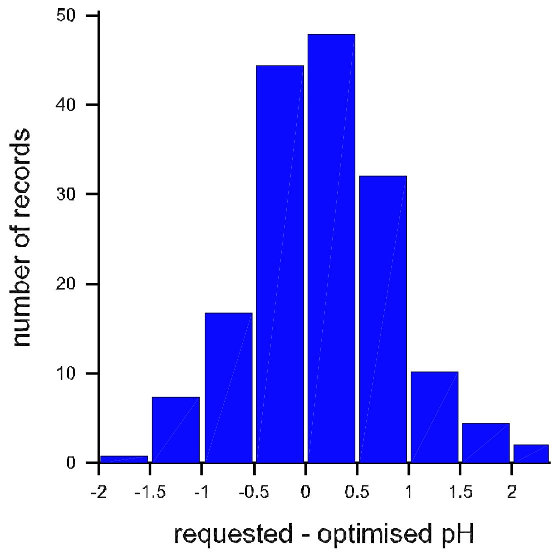

Figure 5: histogram of deviation of optimised pH from requested pH (mean deviation = 0.27 $\pm$ 0.64 units

[*] Throughout this document, deposition is expressed in kg N.ha^{-1}.y^{-1}, and N availability is expressed in kMol.ha^{-1}.y^{-1} (for N, 1 kMol = 14 kg).

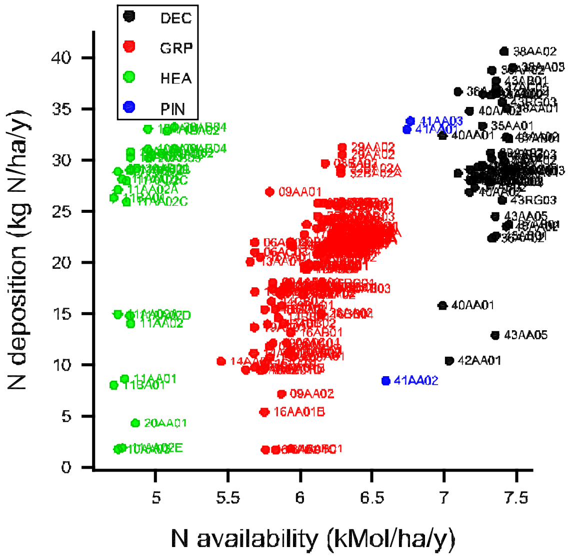

Figure 6: scattergram of N availability against N deposition. Points are at the P_{80} of N availability and the corresponding deposition (= critical load) per association. Colours indicate vegetation structure types (DEC = deciduous forest, PIN = coniferous forest, HEA = heathland, GRP = grassland); explanation of vegetation type coding in Appendix 2.

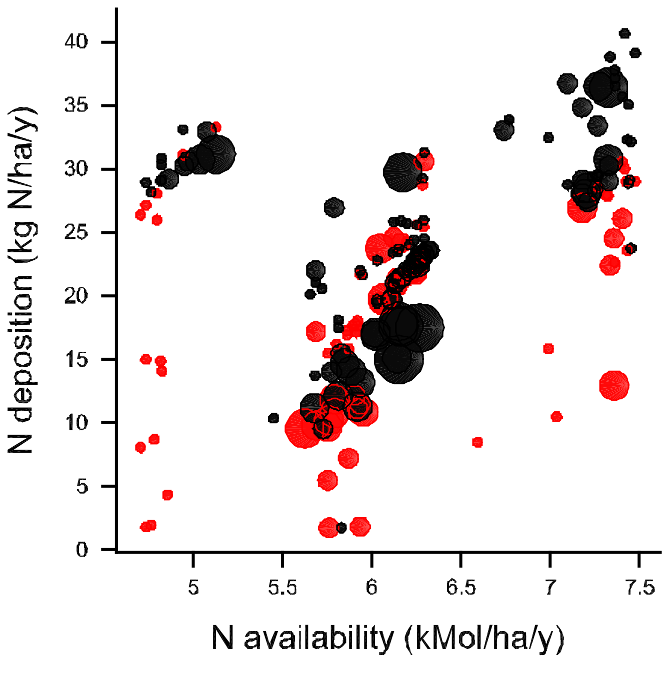

Figure 7: scattergram of N availability against N deposition. Points are at the P_{80} of N availability and the corresponding deposition (= critical load) per association. Dot colour and size indicate the discrepancy between the 'requested' and the 'optimised' pH (red = optimised > requested, black = optimised < requested; largest dot = |optimised - requested| > 2, smallest dot = |optimised - requested| < 0.5.

Table 12: summary of critical loads (in kg N $ha^{-1}.y^{-1}$) per vegetation type and per soil type. Explanation of soil types and vegetation types in Table 3 and 4, respectively; N = number of associations.

Vegtype	Soiltype	mean	±	se	(N)
GRP	SP	12.9	±	3.3	(20)
	SR	17.3	±	3.9	(16)
	SC	20.8	±	2.4	(33)
	CN	22.9	±	3.1	(21)
	CC	23.3	±	2.3	(38)
	LN	13.2	±	*	(1)
	PN	16.8	±	8.7	(19)
	Overall	**19.7**	**±**	**5.4**	**(148)**
HEA	SP	19.9	±	11.6	(17)
	SR	28.2	±	*	(1)
	SC	33.3	±	*	(1)
	PN	29.5	±	2.5	(8)
	Overall	**23.5**	**±**	**10.4**	**(27)**
PIN	**SP**	**25.1**	**±**	**14.4**	**(3)**
DEC	SP	25.6	±	7.1	(9)
	SR	26.6	±	6.1	(7)
	SC	28.5	±	0.6	(6)
	CN	26.1	±	2.7	(9)
	CC	36.5	±	2.8	(10)
	PN	32.9	±	4.8	(8)
	Overall	**29.6**	**±**	**6.1**	**(49)**
All types	SP	18.4	±	9.6	(49)
	SR	20.5	±	6.4	(24)
	SC	22.3	±	3.9	(40)
	CN	23.9	±	3.3	(30)
	CC	26.0	±	5.9	(48)
	LN	13.2	±	*	(1)
	PN	23.4	±	10.0	(35)
	General	**22.4**	**±**	**7.6**	**(227)**

3.3 Sensitivity analysis

Both the critical load and the optimised pH were subjected to a sensitivity analysis by regressing them on the input variables. The results for the critical load are given in Table 13 (regression analysis) and 14 (analysis of variance). Table 14 confirms the impression that the estimated critical load for a large part depends upon the vegetation type, and to a lesser extent on the requested N availability and the soil type. It should be noted that the regression coefficient for N availability does not significantly differ from the expected value of 14 (Table 13). At equal abiotic conditions, the critical load for pine forest is equal to the one for grassland, but the critical load for heathland is significantly higher, and for deciduous forest significantly lower than for grassland (Table 13). However, because of the difference in average abiotic conditions per vegetation type, the final critical loads increase in the order grassland < heathland < pine forest < deciduous forest (Table 12). The effect of soil type on the critical load is rather limited. Both calcareous soil types have a significantly higher critical load than the reference type (poor sand), and also non-calcareous clay and peat have higher critical loads (Table 13). The final order of critical load per soil type (taking account of the distribution of the vegetation types over the soil types) is poor sand < rich sand < calcareous sand < non-calcareous clay < peat < calcareous clay (Table 12). The critical load for löss cannot be determined with any degree of certainty as there is only one record for this soil type. The seepage quality only contributes to a very limited extent to the critical load, and seepage quantity, MPLS and soil pH have no significant contribution at all (Table 13).

Tables 15 and 16 give the results of the sensitivity analysis for pH. The optimised pH is highly significantly related to the requested pH, with a regression coefficient not significantly different from the expected value of 1. After the requested pH, the next most important factor determining the optimised pH is soil type (Table 16), where non-calcareous clay has a significantly higher optimised pH than all other soil types (Table 15). There is also a slight influence of vegetation type and seepage quantity and quality on the optimised pH.

For the regression of both critical load and optimised pH on the input variables the percentage explained variance is below 100%. As there are no other factors influencing the model's output than the ones used as explanatory variables, the deviation of the actual explained variance from 100% must be due to nonlinearity or interaction in the response of the model. Apparently this nonlinearity is rather large for critical load and smaller for pH. The large amounts of explained variance that cannot be uniquely ascribed to any of the input variables (given in the row 'undetermined ' in Table 14 and 16) is caused by the strong correlation among the input variables themselves (e.g. vegetation type and soil, soil and pH, etc).

Table 13: sensitivity analysis of critical load: regression coefficients with standard error and significance determined by Student's t-test for the regression of critical load on the input terms summed up in Table 2. Fitted equation:
$CL = Constant + a_1Seep + a_2MPLS + a_3pH + a_4Nav + SoilType + VegType + SeepQual$
*with CL = critical load in kg N $ha^{-1}.y^{-1}$, Seep = seepage in $mm.day^{-1}$, MPLS = MPLS in cm below soil surface, pH = soil pH, Nav = N availability in $kMol.ha^{-1}.y^{-1}$, and SoilType, VegType, SeepQual are parameters with a single value per class. Number of records: 227. Coding of significance levels: ***= P<0.001; **= 0.001≤P<0.01; *= 0.01≤P<0.05; ns= P>0.05.*

	Term	estimate ± s.e.	
	Constant	-77.8 ± 17.8	***
	seepage quantity	1.246 ± 0.892	ns
	MPLS	-0.0091 ± 0.0202	ns
	pH	-0.145 ± 0.989	ns
	N availability	15.83 ± 3.18	***
soil type[1])	CC	7.23 ± 2.01	***
	CN	4.34 ± 1.58	**
	LN	0.35 ± 5.15	ns
	PN	4.56 ± 1.26	***
	SC	4.52 ± 2.09	*
	SR	1.43 ± 1.41	ns
vegetation type[2])	DEC	-8.99 ± 4.26	*
	HEA	23.3 ± 3.49	***
	PIN	-1.29 ± 4.25	ns
seepage quality[3])	1	-1.91 ± 1.55	ns
	2	-1.88 ± 3.89	ns
	3	-1.04 ± 1.91	ns
	4	-3.73 ± 1.58	*
	5	-3.95 ± 1.42	**

[1]) coding as in Table 3; reference class: SP
[2]) coding as in Table 4; reference class: GRP
[3]) coding as in Table 7; reference class: 0

Table 14: sensitivity analysis of critical load: percentages variance due to each factor determined as bottom marginal variance, i.e. the decrease in explained variance on dropping this factor from the full model. F-value is the regression mean square due to each factor relative to the residual mean square. The value in the row 'undetermined' is calculated by subtracting the sum of the explained variances due to each factor from the total amount of explained variance. Coding of significance levels as in Table 13. Number of records = 227.

	% explained variance	F
full model	56.6	
seepage quantity	0.2	1.95 ns
MPLS	0.0	0.2 ns
pH	0.0	0.02 ns
N availability	4.9	24.72 ***
soil type	3.5	3.85 **
vegetation type	17.4	29.09 ***
seepage quality	1.5	2.46 *
undetermined	29.1	

Table 15: sensitivity analysis of optimised pH: regression coefficients with standard error and significance determined by Student's t-test for the regression of pH on the input terms summed up in Table 2. Fitted equation: pH = Constant + a_1Seep + a_2MPLS + a_3pH + a_4Nav + SoilType + VegType + SeepQual with pH = optimised pH, Seep = seepage in mm.day^{-1}, MPLS = MPLS in cm below soil surface, pH = soil pH, Nav = N availability in kMol.ha^{-1}.y^{-1}, and SoilType, VegType, SeepQual are parameters with a single value per class. Number of records = 227. Coding of significance levels and explanation of footnotes as in Table 13.

	Term	estimate ± s.e.
	Constant	7.92 ± 1.95 ***
	seepage quantity	0.0123 ± 0.0982 ns
	MPLS	-0.00195 ± 0.0022 ns
	PH	1.065 ± 0.109 ***
	N availability	-1.413 ± 0.351 ***
soil type[1])	CC	-0.12 ± 0.222 ns
	CN	0.543 ± 0.173 **
	LN	-1.091 ± 0.567 ns
	PN	-0.148 ± 0.139 ns
	SC	0.172 ± 0.23 ns
	SR	-0.283 ± 0.155 ns
Vegetation type[2])	DEC	1.687 ± 0.468 ***
	HEA	-1.371 ± 0.384 ***
	PIN	1.206 ± 0.468 *
Seepage quality[3])	1	0.343 ± 0.171 *
	2	-0.013 ± 0.428 ns
	3	0.582 ± 0.211 **
	4	-0.05 ± 0.174 ns
	5	0.591 ± 0.157 ***

Table 16: sensitivity analysis of optimised pH: percentages variance due to each factor determined as bottom marginal variance, i.e. the decrease in explained variance on dropping this factor from the full model. F-value is the regression mean square due to each factor relative to the residual mean square. The value in the row 'undetermined' is calculated by subtracting the sum of the explained variances due to each factor from the total amount of explained variance. Coding of significance levels as in Table 13. Number of records = 227.

	% explained variance	F
full model	81.72	
seepage quantity	0.00	0.02 ns
MPLS	0.00	0.77 ns
pH	8.29	95.84 ***
N availability	1.33	16.24 ***
soil type	3.28	7.42 ***
vegetation type	0.95	4.68 **
seepage quality	2.16	6.05 ***
undetermined	65.71	

3.4 Uncertainty analysis

The results of the uncertainty analysis per association are given in Appendix 3. The contribution of the USV to the uncertainty appears to be very large, in the order of 10 - 20 kg N $ha^{-1}.y^{-1}$. When the USV is not taken into account, the overall uncertainty in the critical load is rather small, in the order of 0.2 - 0.6 kg N $ha^{-1}.y^{-1}$. This is visualised for an example in Figure 8. However, in some cases the uncertainty in the critical load is much higher even when USV is not taken into account, in the order of 1 - 10 kg N $ha^{-1}.y^{-1}$. This is the case for e.g. Ericetum tetralicis orchidetosum (11AA02E) or Leucobryo-Pinetum (41AA03). The mean critical load for the 100 runs per association / soil combination applied in the uncertainty analysis is also given in Appendix 3, together with the critical load for the single run using mean parameter values (which are identical to the values in Appendix 2). Usually the difference between these two estimates for the critical load is small (less than 0.5 kg N $ha^{-1}.y^{-1}$). However, for some associations where the uncertainty is large, this difference is also very large (up to 17 kg N $ha^{-1}.y^{-1}$). These are probably records for which there is no unique deposition value that leads to the requested combination of pH and N availability.

Before comparing the results of the present study with other critical load estimates, the reliability of the present estimates has been evaluated using three criteria:

- the critical loads produced by the uncertainty runs **without** taking account of USV should have a standard error of less than 5 kg N $ha^{-1}.y^{-1}$;
- the difference between the critical load estimated on the basis of mean values per parameter (Appendix 2) and the mean value of the uncertainty runs (Appendix 3) should be less than 5 kg N $ha^{-1}.y^{-1}$;
- the critical load values themselves should be within an acceptable range, i.e. larger than 4 kg N $ha^{-1}.y^{-1}$.

In these criteria the USV was deliberately not taken into account, because the USV reflects site-to-site variation, whereas the critical load is assumed to reflect a generalised response. There were 16 associations that did not meet the above criteria; their critical load estimates are given between brackets in Appendix 2, and they were not used for the evaluation of the present critical loads in the light of empirical critical loads and Nature Target Types.

A statistical analysis of the output of the uncertainty analysis was performed to estimate the relative importance of the various sources of uncertainty. Table 17 gives the 'bottom marginal variance' (i.e. the loss in explained variance when dropping a single term from the full regression model) for both the parameters and the USV of each translation function, averaged over all combinations of vegetation and soil type. The uncertainly due to the USV in the translation function for e_N appears to have by far the largest contribution. In fact, all other sources of uncertainty are negligible compared to this one.

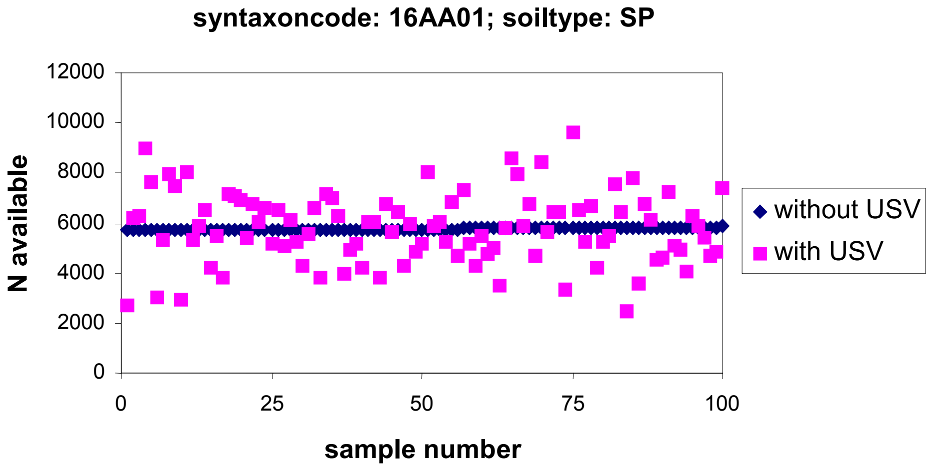

Figure 8: visualisation of the effect of USV on uncertainty. The plot gives the scatter of 100 possible N availabilities for a single combination of soil and vegetation type, with and without accounting for the USV.

Table 17: contribution of the parameters and USV of the three translation functions to the uncertainty, based on regression analysis using smoothing splines. Numbers relate to 'bottom' marginal variances, i.e. the drop in explained variance when omitting the term given from the full regression model. The regression model was
$CL = C + SPL(P_{MPLS} + USV_{MPLS}) + SPL(P_{pH} + USV_{pH}) + SPL(P_{Nav} + USV_{Nav})$
with CL = critical load, SPL = spline function with 2 df, C = constant, P = parameter values drawn from distribution (as described in 2.3.3), USV = USV values drawn from distribution (as described in 2.3.3), subscipts denote the three translation functions for MPLS, pH and N availability, respectively. Note that P stands for 2, 2 and 5 parameters of the respective translation functions.
The model was fitted for all 228 vegetation /soil combinations, using 100 samples per combination. Figures given are bottom marginal variances averaged over the vegetation / soil combinations. Note that for the calcareous soil types the translation function for pH does not contribute to the uncertainty as in these types the pH was fixed at 7.

translation function	% variance due to:	
	parameters	USV
MPLS	0.07	0.61
pH	0.08	0.20
N availability	0.54	88.56
total % expl. variance	90.79	

4 Discussion

4.1 Methodological constraints

The sensitivity analysis showed that of all input variables, vegetation type and N availability most strongly contribute to the simulated critical load. Of these two, the N availability has by far the largest uncertainty because it is derived from Ellenberg numbers and a translation function that has a large amount of intrinsic uncertainly. In the calibration of the translation function the implicit assumption was made that the relevees in the training set have a N availability equal to the average sum of mineralisation and deposition in over the period 1950 - 1990. Or in other words: for each association the assumption is made that the thus estimated N availabilities represent the range of N availabilities that is characteristic for that association, or at least, that the upper end of this range (determined as P_{80}) is its limit of occurrence. For the present critical loads this had two consequences:

(1) if the historic deposition is over- or underestimated, the critical loads will be over- or underestimated by the same amount; and

(2) the implicit assumption is made that the historic relevees represent each association in an optimally developed form. If the historic deposition has already caused a certain loss of biodiversity, this will remain unnoticed in the present method, and will ultimately lead to an over-estimation of the critical load. Even from the early 19th century onward, species have been lost to the Dutch flora, especially in grasslands (Weeda et al. 2002, pp. 77-79 and 175-176), and indications exist that this loss may be partly ascibed to atmospheric deposition (Westhoff & van Leeuwen 1959, van Dam et al. 1984). It should be noted that if this causes a bias in the estimated critical load, the same bias probably occurs in the empirical critical loads, because here the notions of biodiversity and the optimal development of vegetation types are also strongly related to the vegetation of the period just before the strong increase of deposition started (i.e., before ca. 1965).

Another consequence of the way in which e_N is translated into N availability is that it creates a certain independence of the formulation of the mineralisation process in SMART2. E.g. if SMART2 over-estimates N mineralisation, this will lead to an over-estimation of N availability at a given value of e_N, but this will be compensated in $SMART2^{-1}$ because the requested N availability will then also be over-estimated, and thus the amount of N that is to be provided by deposition will still be correctly estimated.

Although there are sometimes large discrepancies between the optimised and the requested pH (Figure 5), these do not seem to influence the critical load. In the sensitivity analysis the effect of pH on critical load was not significant, and there was no consistent pattern in the relation between requested N availability, critical load and deviation of the optimised pH from the requested value (Figure 7). The discrepancy between the requested and the optimised N availability in heathland on poor sand (Figure 3) is probably caused by the combination of a high requested N availability and a high pH on a soil with a low buffering capacity. This causes the optimisation procedure to suppress the N input in order to realise the requested pH. That in these particular ecosystems the optimisation procedure does not lead to the requested results (for pH and N availability at the same time), is due to 'inconsistent' combinations of soil type, requested pH and N availability. Taking into account all relevant buffering processes as included in SMART2, it is not feasible to establish a relatively high pH in poor sandy soil at a high input of acidity. The extremely low optimised N availability results in an extremely low critical load, however critical load values below 4 kg N $ha^{-1}.y^{-1}$ have been removed from the data before a comparison with other methods took place (see 3.4).

4.2 Uncertainty

The uncertainty analysis showed a very large contribution of USV to the total uncertainty. The USV is a reflection of the overall variability in the input data of $SMART2^{-1}$. As the contribution of the translation function of N availability is by far the largest, this means that at a given value for Ellenberg-N, the N availability estimated by the present method (described in paragraph 2.2.6) has a very large variability, i.e. the N availabilities are strongly different per record (vegetation relevee of a given association / soil combination). This variability may in itself have two causes: (1) it may be 'real', in which case a given association may occur at widely different N availabilities, or (2) it may be 'artificial', in which case the method used to estimate N availability yields values that have a large spread at any given 'real' N availability. On the basis of the present data it is not possible to decide which of these causes mostly contributes to the USV. In case (2) it may be hypothesised that the estimated N availability is close to the real value if the average over a large number of observations is taken; the remaining uncertainty in this average is reflected by the uncertainty **without** USV. In case (1) the USV reflects the intrinsic variability in the response of the vegetation to N availability (possibly caused by variation in other environmental factors); i.e., the large USV reflects a large site-to-site variation in 'real' critical load. In that case it could be argued that the aim of the present study was to derive critical loads per association, i.e. average values over the range of environmental conditions where each association may occur. Also in that case the uncertainty in the average values, i.e. the uncertainty **without** USV, is most relevant. For these reasons, USV was not taken into account in the evaluation of the reliability of the critical load estimates (resulting in the values considered 'less reliable' in Appendix 2). However, in case (1) the large USV must be considered as a warning that the estimated critical loads have no absolute meaning, because the 'real' possibilities for an association to occur may be strongly governed by other environmental factors besides deposition. If that is the case, an association can still occur at values far above the critical load if other conditions are favourable, and the absolute values given in Appendix 2 should only be considered as indicative, although they still may give a good impression of the differences in sensitivity between the associations.

Table 17 gives a clear indication of research required to reduce the uncertainty in the critical load: both the parameters and the USV of the translation function for N availability have by far the largest contribution to uncertainty. It seems rather unlikely that other sources, not considered in this study, have a larger contribution to the uncertainty. Such sources could be the model structure and parameterisation of SMART2^{-1}; however this model has been extensively tested and validated against 'real' observations (Kros 2002). The method to estimate N availability per relevee used in this study is rather indirect: it makes the assumption that Ellenberg-N gives a good initial estimate of N availability, and subsequently attempts to calibrate Ellenberg-N against N availabilities estimated on the basis of the relevee's geographical position and historic deposition. The intrinsic uncertainty in Ellenberg values has been extensively discussed by Wamelink et al. (2002) and Wamelink & van Dobben (2003), and the uncertainties in the estimated historic N availabilities are self-evident. Therefore the most urgent research need seems to establish a better relation between the occurrence of species or communities (associations) and N availability in the field. If such data are sufficiently available it will also be possible to track down the cause of the large USV, i.e. methodological, or real variability in biotic response.

4.3 Comparison with Nature Target Types

The critical loads per Nature Target Type (NTT, in the sense of Bal et al. 2001) were determined on the basis of the 'determinative' ('beeldbepalende') associations for each NTT, as given by Bal et al. (2001) in their descriptions per NTT. In cases where NTTs are described for one or more specific soil types, the critical loads for the associations on that soil type(s) were used; otherwise values from all soil types were used. Appendix 4 gives the minimum and maximum of the critical load values of each NTT's constituent association - soil combinations. Theoretically, the NTT can occur at the maximum of the critical load range; in that case represented by one 'determinative' association (in a number of cases, only on a certain soil type); whereas the NTT can only be fully developed at values below the minimum of the critical load range. However, this is only the case if the critical loads in Appendix 2 are 'absolute values', i.e. if their uncertainty is very small. Such small uncertainties are only found when USV is left out of consideration (see 4.2). If the uncertainty with USV has to be considered as the 'real' uncertainty (which is the case if there is a large site-to-site variability in the response of each association to N deposition), the ranges become far larger (by at least 15 kg N $ha^{-1}.y^{-1}$, the order of magnitude of the s.e. of the critical load when USV is taken into account). This would mean that for most NTTs the critical load range comes in the order of 5 - 40 kg N $ha^{-1}.y^{-1}$, which would reduce the practical applicability of the present analysis. On the other hand this would mean that any reduction in deposition, even to values well above the mean critical load, will have positive effects. As argued in section 4.2, only the collection of additional field data on the abiotic response of each association would reduce these uncertainties. Moreover such field data can be used to determine the cause of the large USV, and thereby give an answer to the question whether the uncertainty has to be considered with or without taking USV into account.

4.4 Comparison with other critical load estimates

The critical loads estimated in this study were compared to those estimated in earlier simulation studies that used a dynamic model by van Hinsberg & Kros (1999) (the 'Herijking' method) and by Schouwenberg et al. (2000a), to results obtained by a simple steady-state model (the 'SMB' method, De Vries 1993, Sverdup & de Vries 1994), and to empirical values reported by Achermann & Bobbink (2003). With the exception of Schouwenberg et al., all these studies used different forms of vegetation classification, and for a comparison the results of the present study had to be recalculated. Table 18 gives an overall comparison of the present results with those of other studies. Details of these comparisons are given below.

Table 18: comparison of critical loads derived in this and other studies. Values are parameters of the regression equation
$CL(other) = a_0 + a_1CL + a_2CL^2$
with CL(other) = critical load derived in other study; CL = simulated critical load derived in this study; fit = percentage explained variance, F = F-ratio and significance, diff = mean difference [CL(other) - CL] and significance of difference as determined by Student's paired t-test, n = number of units (significance coded as in Table 13).

method	a_0	a_1	a_2	fit	F	diff	n
$SMART2^{-1}$ + MOVE	6.90	0.623	-	16.2%	11.03 **	-1.5 ^{ns}	53
$SMART2^{-1}$ + Ellenberg based critical limits per association	-16.32	3.573	-0.056	22.6%	20.37 ***	+10.1 ***	137
Steady-state mass balance model	2.56	0.35	-	6.4%	2.02 ^{ns}	-13.0 ***	16
Empirical data	17.08	-0.024	-	0%	0.01 ^{ns}	-3.4 ^{ns}	22

4.4.1 Critical loads based on $SMART^{-1}$ and MOVE

This method used a two-step approach comparable to the present method. In the first step the Multiple stress mOdel for the VEgetation (MOVE) was used to calculate the critical limits for the 130 nature target types in the sense of Bal et al. (1995), as described by Latour et al. (1994, 1997). The critical limits were based on habitat preferences per species for nitrogen availability and soil pH, derived from Ellenberg numbers. The critical limits for the nature targets were defined in terms of the highest tolerable nitrogen availability and the lowest tolerable soil pH for an acceptable number of species. In the second step SMART2 was used to calculate the critical loads at which the above critical limits were not exceeded. In order to relate critical limits to critical deposition levels, relationships between deposition, nitrogen availability and soil pH were derived by regressing SMART2's input on its output, using a large set of model runs that was assumed to represent all possible input combinations. The ratios between NO_x, NH_y, and SO_x deposition were assumed similar to their values in 1995. In cases where this method failed, the lowest empirical critical loads from similar ecosystems (Bobbink et. al. 1996) were used.

For a comparison, the results of the present study were recalculated to mean values over the associations constituting each NTT, taking account of the soil types per NTT (analogous to the procedure described in 4.3 but using NTTs in the sense of

Bal et al. 1995 instead of Bal et al. 2001). The results of both studies are compared in Figure 9. The critical loads derived by this study are slightly lower than those of the present study, but the difference is not significant and the critical load values per NTT are significantly correlated (P<0.01, Table 18).

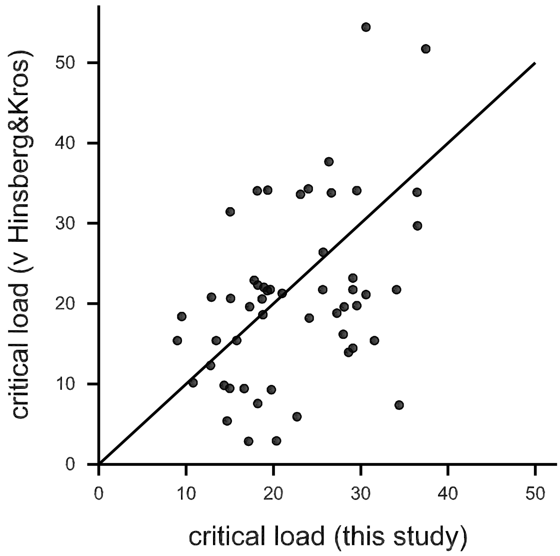

Figure 9: comparison of the results of van Hinsberg & Kros (1999) ('herijking') with those of the present study. Values are kg N $ha^{-1}.y^{-1}$, drawn line is 1:1.

4.4.2 Critical loads based on $SMART2^{-1}$ and critical limits per association

This method is equal to the previous one, except that the critical limits were determined per association instead of per NTT, using estimates based on vegetation relevees, Ellenberg numbers and translation functions. It is also equal to the present method except that a different parameterisation of the Ellenberg translation functions was used, and an older version of $SMART2^{-1}$ based on inverse regression rather than on optimisation. Because this method was based on associations like the present one, the comparison can be straightforward in this case. The result is given in Figure 10. Schouwenberg's critical loads are significantly correlated to those of the present study (P<0.001), but his values are systematically higher than the present ones (mean difference ca. 10 kg N $ha^{-1}.y^{-1}$, Table 18). The most important cause of this difference is probably the different parameterisation used for E2P, especially the 'flatter' response of the vegetation to N availability in the present study (Figure 2).

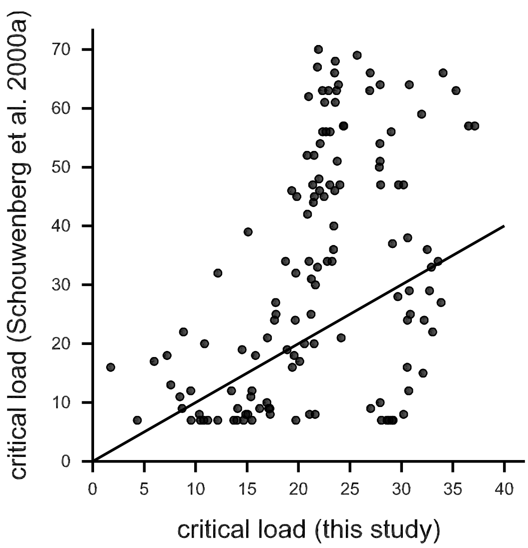

Figure 10: comparison of the results of Schouwenberg et al (2000a) with those of the present study. Values are kg N $ha^{-1}.y^{-1}$, drawn line is 1:1.

4.4.3 Critical loads based on the SMB model

The 'Simple Mass Balance' method described by e.g. de Vries (1993) and Posch et al. (2001) has a soil-oriented steady state approach. Its assumption is that at or below the critical load, all deposited nitrogen is taken up by the vegetation, immobilised, denitrified, and leached in an acceptable amount. The critical load can then be simply calculated according to:

$$CL(N) = N_{gu} + N_{im} + N_{le(acc)}/(1\text{-}f_{de}) \quad (4)$$

with CL(N): critical load for N, N_{gu}: net uptake of N by the vegetation, N_{im}: net N immobilisation, $N_{le(acc)}$: acceptable amount of N leaching, f_{de}: fraction of N that is denitrified.

These parameters were estimated for all unfertilised 1 X 1 km^2 squares in the Netherlands using the dominant soil and vegetation types per square. N_{gu} was estimated on the basis of the soil type, the vegetation type and the groundwater level; f_{de} was estimated on the basis of the soil type and the groundwater level; N_{im} was set to a constant value of 0.2 $kMol_c.ha^{-1}.y^{-1}$ (≈0.2% increase over 0-30 cm and 100 years); and $N_{le(acc)}$ was estimated on the basis of the precipitation excess per square and an acceptable concentration of 0.05 $Mol_c.m^{-3}$ (≈3 mg NO_3/l) at the bottom of the root zone. The latter estimate is based on expert judgement, and is in fact very weakly substantiated. This is a weakness of the SMB method, as the estimated critical load is very sensitive to the critical or acceptable leaching rate, as can be seen from equation (4).

Table 19: critical loads in kg N ha^{-1}.y^{-1} derived by the SMB method for the Netherlands. Explanation of soil types and vegetation types in Table 3 and 4, respectively; N = number of km^{2} squares with this soil and vegetation as the dominant type.

Vegtype	Soiltype	Mean ± Se	(N)
GRP	SP	6.2 ± 1.8	(3343)
	SR	6.4 ± 0.8	(2094)
	SC	4.7 ± 3.4	(836)
	CN	9.9 ± 3.5	(1127)
	CC	8.1 ± 4	(1136)
	LN	7.2 ± 1.4	(112)
	PN	26.3 ± 5.2	(1881)
	Overall	10.5 ± 8.5	(10529)
HEA	SP	4.4 ± 0.9	(1557)
	SR	5.4 ± 0.7	(179)
	PN	18.3 ± 3.9	(358)
	Overall	6.9 ± 5.6	(2109)
PIN	**SP**	7.2 ± 0.4	(5457)
DEC	SP	9.9 ± 0.7	(3980)
	SR	11.5 ± 0.9	(2398)
	SC	9.7 ± 1.5	(339)
	CN	11.7 ± 2.4	(1121)
	CC	10.5 ± 1.3	(561)
	PN	23.9 ± 5.2	(883)
	Overall	11.8 ± 4.4	(9509)
All types	SP	7.3 ± 1.8	(15581)
	SR	8.8 ± 2.5	(5893)
	SC	5.8 ± 3.6	(1271)
	CN	10.6 ± 3.2	(2367)
	CC	8.9 ± 3.6	(1708)
	LN	10.4 ± 2.3	(389)
	PN	24.2 ± 5.9	(3287)
	General	9.4 ± 5.8	(30496)

The comparison was made by calculating the average critical load per combination of soil type and vegetation type (Table 19), and plotting these against the values given in Table 12. The result is given in Figure 11. The mean critical load derived by the SMB method appears to be far lower than the one derived in the present study, the difference being 13 kg N ha^{-1}.y^{-1} which is highly significant ($P<0.001$; Table 18). Furthermore there appears to be no significant correlation between the critical loads per soil / vegetation combination in the two methods ($P>0.1$, Table 18). The SMB critical loads are lower than those of the present study for all soil / vegetation combinations except grassland on peat. This is most likely caused by the acceptable leaching rates, which are much lower than those that follow from SMART2^{-1}, where the N availability is the driving critical variable. Furthermore, the long term acceptable critical N immobilisation rate calculated with SMB is most likely smaller than the N immobilisation rate calculated by SMART2^{-1}, using a time period of several decades (and no steady state).

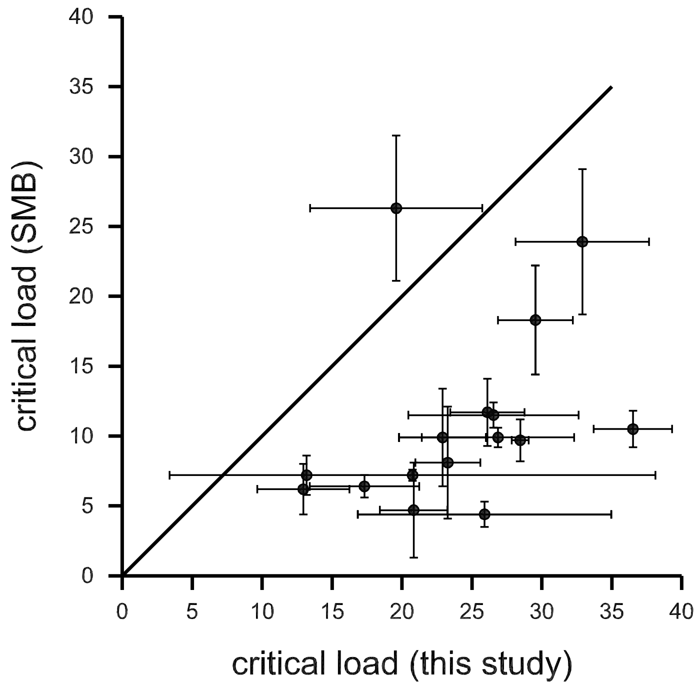

Figure 11: comparison of the critical loads estimated by the SMB method for soil / vegetation type combinations in the Netherlands, and critical loads estimated in this study. Values are kg N ha^{-1}.y^{-1}, error bars are standard errors, drawn line is 1:1.

4.4.4 Empirical critical loads

The result of a comparison of empirical critical load data after Achermann & Bobbink (2003) and the calculations made in this study are shown in Table 20. As there is no one to one translation of the EUNIS classification (Davies & Moss 2002) used by Achermann & Bobbink (2003) to the syntaxonomic classification used in our study, a comparison with this study could only be made in a general way. As the EUNIS classification at the level used by Achermann & Bobbink is much coarser than the syntaxonomic classification at the level of association, the EUNIS classes were translated into combinations of vegetation structure and soil type rather than into associations (Table 20). Critical load ranges were assigned to these combinations on the basis of the association's vegetation types (in the sense of SMART2, Appendix 1), and the minimum and maximum critical load values per soil - association combination (Appendix 2). This was done without taking account of the uncertainty, however the critical loads that were considered less reliable (in brackets in Appendix 2, cf. 3.4) were left out of consideration. As Achermann & Bobbink do not give EUNIS classes for forest types, the structure types pine forest (PIN) and deciduous forest (DEC) were taken together, and their critical load was compared to the critical load of 'ground vegetation' in Achermann & Bobbink. The critical load given by Achermann & Bobbink for 'lichens and algae' was compared to the one derived in our study for lichen-rich pine forest (Cladonio-Pinetum sylvestris). The marine habitats in Achermann & Bobbink were compared to the vegetation types that have seepage quality class 4 (seawater) in our study.

*Table 20: comparison of simulated and empirical critical loads per EUNIS class. Empirical data are taken from Bobbink et al. (2003); ## = reliable, # = quite reliable, (#) is expert judgement. * = EUNIS class does not occur in the Netherlands. Values are kg N $ha^{-1}.y^{-1}$. Translation of EUNIS classes to soil and vegetation types was done on the basis of expert judgement. Correspondence between simulated and empirical critical loads is given in the last column: < = simulated range below empirical range, > = simulated range above empirical range, = = ranges overlap.*

Ecosystem type	EUNIS-code	empirical critical load	reliability	vegetation type	soil type	simulated critical load	simulated compared to empirical
Forest habitats (G)							
Ground vegetation (Temperate and boreal forests)	-	10-15	#	DEC, PIN	all types	8-41	=
Lichens and algae (Temperate and boreal forests)	-	10-15	(#)	[1])		8-9	<
Heathland, scrub and tundra habitats (F)							
Tundra	F1	5-10	#	*			
Arctic, alpine and subalpine scrub habitats	F2	5-15	(#)	*			
Northern wet heath:	F4.11						
‘U’ Calluna-dominated wet heath (upland moorland)	F4.11	10-20	(#)	HEA	SP, PN	4-33	=
‘L’ Erica tetralix dominated wet heath	F4.11	10-25	(#)	HEA	PN	26-33	>
Dry heaths	F4.2	10-20	##	HEA	SP	4-31	=
Grasslands and tall forb habitats (E)							
Sub-atlantic semi-dry calcareous grassland	E1.26	15-25	##	GRP	SC, CC	15-31	=
Non-mediterranean dry acid and neutral closed grassland	E1.7	10-20	#	GRP	SR, CN	10-31	=
Inland dune pioneer grasslands	E1.94	10-20	(#)	GRP	SP	10-21	=
Inland dune siliceous grasslands	E1.95	10-20	(#)	GRP	SP	10-21	=
Low and medium altitude hay meadows	E2.2	20-30	(#)	GRP	SR, CN	10-31	=
Mountain hay meadows	E2.3	10-20	(#)	*	*		
Moist and wet oligotrophic grasslands:	E3.5						
Molinia caerulea meadows	E3.51	15-25	(#)	GRP	SP, PN	5-30	=
Heath (Juncus) meadows and humid (Nardus stricta) swards	E3.52	10-20	#	GRP, HEA	SP, PN	4-33	=
Alpine and subalpine grasslands	E4.3 and E4.4	10-15	(#)	*	*		

Ecosystem type	EUNIS-code	empirical critical load	reliability	vegetation type	soil type	simulated critical load	simulated compared to empirical
Moss and lichen dominated mountain summits	E4.2	5-10	#	*	*		
Mire, bog and fen habitats (D)							
Raised and blanket bogs	D1	5-10	##	HEA	PN	26-33	>
Poor fens	D2.2	10-20	#	GRP	PN	5-30	=
Rich fens	D4.1	15-35	(#)	GRP	PN, SC	5-30	=
Mountain rich fens	D4.2	15-25	(#)	*	*		
Inland surface water habitats (C)							
Permanent oligotrophic waters:	C1.1						
Softwater lakes	C1.1	5-10	##	[2])		21-22	>
Dune slack pools	C1.16	10-20	(#)	[3])		12-13	=
Coastal habitat (B)							
Shifting coastal dunes	B1.3	10-20	(#)	GRP	SC	15-24	=
Coastal stable dune grasslands	B1.4	10-20	#	GRP	SC	15-24	=
Coastal dune heaths	B1.5	10-20	(#)	HEA	SC, SR	33-34	>
Moist to wet dune slacks	B1.8	10-25	(#)	GRP	SC, SR	10-24	=
Marine habitats (A)							
Pioneer and low-mid salt marshes	A2.64 and A2.65	30-40	(#)	[4])		21-24	<

1) only Cladonio-Pinetum sylvestris
2) only Eleocharitetum multicaulis
3) only Samolo-Littorelletum
4) all marine and saltmarsh communities

To make a comparison, midpoints were determined as the mean of the lower and upper limits for the ranges of both our study and that of Achermann & Bobbink. Although the simulated critical loads appear to be in the same order of magnitude as the empirical critical loads (Table 20), the midpoint values per EUNIS class are not correlated (Table 18). For most EUNIS classes the ranges of the critical loads determined by both methods overlap, although the empirical values are generally slightly below the simulated ones (mean difference of range midpoints is 3.4 kg N $ha^{-1}.y^{-1}$ which is nearly significant [P≈0.07]; Table 18). This difference might be due to the nature of the experiments used to determine the empirical values which are usually before-after (so-called 'BACI') studies or time series, where small changes caused by deposition are easily noted. The abiotic ranges as used for the simulated critical loads probably provide a coarser measure to determine whether there is an effect of deposition. Furthermore, the empirical critical loads tend to be based on the most sensitive components of each ecosystem, often under abiotic conditions that enhance sensitivity still further (cf. Bobbink et al. 2003).

For the following EUNIS-classes the ranges of the empirical and simulated critical loads do not overlap (compare Table 20): forest (lichens and algae) and pioneer and low-mid salt marshes (simulated critical load < empirical critical load); and raised and blanket bogs, softwater lakes, and coastal dune heaths (simulated critical load > empirical critical load). With the exception of Cladonio-Pinetum which has a very large uncertainty (Appendix 3), and the marine habitats, the simulated critical load is above the empirical value for these classes.

4.5 Policy implications

Five conclusions of the present study may have important consequences for policy:
1. dynamic models linked with field information on the species' response to environmental factors allow the calculation ('simulation') of critical loads per vegetation type, including their uncertainty;
2. the uncertainty in the simulated mean critical load per vegetation type is small;
3. the overall empirical and simulated critical loads are in the same range;
4. there is no correlation between the empirical and simulated critical loads per vegetation type (EUNIS class);
5. the uncertainty in the simulated critical loads per site is very high.

Conclusions (1), (2) and (3) increase the confidence in the critical load concept, as the uncertainty in the mean critical load per vegetation type is low, and two completely different methods to estimate the critical load yield approximately equal results. This makes the critical load concept a useful tool for international policy. The present method also allows the determination of the effect of abiotic circumstances (e.g. soil type or groundwater level) that modify the critical load. Although tables of empirical critical loads sometimes give an indication of the effect of such modifying factors, simulation allows the estimation of their effect with a greater accuracy. However, conclusions (4) and (5) raise the question whether a differentiation of critical loads between vegetation types or sites can be made at the present state of knowledge. In fact, these conclusions indicate that it is not feasible to use such a differentiation for optimisation of environmental policy at a sub national level.

The present state of knowledge can be summarised as follows:

- a critical load in the order of 10 - 30 kg N $ha^{-1}.y^{-1}$ for most vegetation types in The Netherlands can be considered as a 'hard' number. Almost all EUNIS classes have empirical critical loads in this range, and also an earlier study in the Netherlands ('herijking verzuringsdoelstellingen') produced values in this range;
- the critical load values per Nature Target Type (NTT) are less 'hard'. This is true even though the uncertainty in the simulated values is low, since for some NTTs the simulated critical loads are clearly different from the empirical critical values;
- it is not possible to determine critical load values on a local scale, as the uncertainty in simulated values becomes very high in that case, and empirical values are not available at that level of detail. However, the uncertainty of simulated critical loads decreases as the geographical scale increases. Therefore, calculated exceedances at large scales like the squares of 50 X 50 km^2 used in UN-ECE studies can be considered robust, since at that level usually many vegetation and soil types are present. However, it is clear that at that resolution, the detailed pattern in deposition and in sensitivity of the vegetation is lost.

The uncertainty in the simulated critical loads is primarily caused by the high 'unexplained system variance' (USV), which in turn is caused by a strong variability in the response of the vegetation to N availability, as determined in this study. This high variability may have several causes:

- the variability is real, i.e. there is a strong random fluctuation in the response of the vegetation to N availability; or
- there is a strong interaction, i.e. the response of the vegetation to N availability strongly depends on other factors like groundwater level or development stage of the vegetation; or
- the variability is only apparent, i.e. it is caused by a weak relation between the N availability as estimated by the (indirect) method used in this study, and the real N availability.

It is not possible to differentiate between these causes on the basis of the present data. In the case that the variability is 'real', i.e. represents random variation, the critical load concept has its limitations at small spatial scales. In that case the critical loads per NTT can be considered reliable as a mean values, but they have little predictive power when individual sites are concerned. However, this would also mean that a general reduction of deposition will have beneficial ecological effects even if the critical load is still exceeded on a large scale, because some sites will have a critical load value far above the mean value for its vegetation type. In that case any reduction in deposition might have a positive effect, and indications for this were found by de Vries et al. (2002).

If the variation is due to interaction or has methodological causes, it can be reduced by new field observations. In general, the largest uncertainties in the present study are caused by a lack of standardised field observations on the response of the vegetation to environmental factors. The low percentages of explained variance in the regression of mean Ellenberg values on environmental variables (Tables 5 and 6) bear witness to this. Of course there is also uncertainty in SMART2's structure and parameterisation, however this model has been extensively validated against field data and therefore its contribution to uncertainty is considered of minor importance.

4.6 Research recommendations

In the light of the above, a research priority indicated by this study is a systematic inventory of vegetation response to master environmental factors in the field. These master factors are: soil pH, availability of water, and availability of nitrogen (or, in general, availability of nutrients). If better information on these responses were available, it would be possible to discriminate between the causes of the uncertainty summed up above. In the case the variability would be caused by interaction with other environmental factors it would be possible to decrease uncertainty by taking these factors into account. The acquisition of such data requires that vegetation relevees are made together with measurements of soil chemistry and groundwater table.

Earlier studies (e.g., Sanders et al. 2000 or Wamelink et al. 2002) have shown that available field data are qualitatively and quantitatively insufficient to fill the above gap. Common problems are:

- lack of standardisation (sample depth, analytical methods etc.);
- lack of insight into the reliability of the data (many are from student's reports);
- lack of possibilities to determine interaction (usually, only one factor is measured at a time);
- insufficient or missing data for many vegetation types.

These shortcomings results in a large uncertainty in the translation of Ellenberg numbers into physical units, especially in the case of e_N (N availability). Also, the Ellenberg numbers appear to contain considerable bias (Wamelink et al. 2002). Ultimately, it would be desirable to replace Ellenberg numbers by response estimates that are solely based on measurements. The accomplishment of such a goal would require a large research effort, but the applicability of the resulting data stretches far beyond the field of critical loads alone. Not only would all ecological models strongly benefit by such data, but also practical terrain management has a strong need for better response data. Also, the interpretation of biotic time series, e.g. on decrease or increase of species, would gain in reliability if better response data were available. It is therefore recommended to carry out a definition study to solve practical problems in the field of e.g. measurement methods, locations, financial inputs etc. before starting the actual measurements. In order to increase the feasibility of such a study the possibility should be examined to incorporate these measurements in existing biotic measurement networks e.g. the Network Ecological Monitoring (NEM). In that case, such biotic networks would profit from a wider availability of data at their measurement locations.

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Appendix 1 input to SMART^{-1}.

Each combination of syntaxon and soil type constitutes a record (total number of records: 228).

The font of the soil code indicates its origin: NORMAL = from overlay of relevees and soil map, *ITALIC* = from expert knowledge, **BOLD** = from both map overlay and expert knowledge.

syntaxon code	soil	vege-tation type	seepage quality	seepage quantity	MPLS	pH	N availa-bility	syntaxon
according to Schamenee &al	see Table 3	see Table 4	see Table 7	mm/day	cm below soil surface	-	kMol/ ha/y	according to Schamenee&al
06AC03	PN *SP*	GRP	0	3	40.0	4.42	5.69	Eleocharitetum multicaulis
06AC04	***SP***	GRP	1	0.1	42.5	5.60	5.91	Samolo-Littorelletum
07AA02	*SR*	GRP	2	5	73.4	5.59	6.09	Pellio epiphyllae-Chrysosplenietum oppositifolii
08AB01	*CC*	GRP	5	2	23.0	7.00	6.25	Rorippo-Oenanthetum aquaticae
08BA02	***PN***	GRP	1	0.1	29.4	6.32	6.17	Cicuto-Caricetum pseudocyperi
08BB03A	*CC* CN *PN* *SR*	GRP	3	2	17.3	7.00	6.25	Alismato-Scirpetum scirpetosum triquetri
08BB04	*CC* CN ***PN***	GRP	5	2	44.4	7.00	6.19	Typho-Phragmitetum
08BC02	*CC* CN *PN*	GRP	5	2	45.9	7.00	6.16	Caricetum gracilis
09AA01	*PN* SP	GRP	1	0.1	42.9	5.30	5.79	Caricetum trinervi-nigrae
09AA02	***PN***	GRP	1	0.1	66.2	4.96	5.87	Pallavicinio-Sphagnetum
09AA03	***PN*** *SR*	GRP	1	0.1	52.4	4.85	5.81	Carici curtae-Agrostietum caninae
09BA01	***PN***	GRP	5	1	48.4	5.83	5.87	Scorpidio-Caricetum diandrae
09BA03	*SC*	GRP	2	1	77.2	7.00	5.89	Parnassio-Juncetum atricapilli
09BA04	***SC***	GRP	2	1	75.6	7.00	5.91	Junco baltici-Schoenetum nigricantis
09BA05	***CC*** CN	GRP	5	1	85.5	7.00	5.93	Equiseto variegati-Salicetum repentis
10AA01	*PN* SP	HEA	0	3	17.3	4.16	4.94	Sphagnetum cuspidato-obesi
10AA02	*PN* SP	HEA	0	1	48.6	4.05	4.73	Sphagno-Rhynchosporetum
10AA03	*PN* SP	HEA	0	2	47.6	4.16	4.82	Caricetum limosae
11AA01	***SP***	HEA	0	1	56.3	3.95	4.78	Lycopodio-Rhynchosporetum
11AA02	*PN* ***SP***	HEA	0	1	89.0	3.89	4.82	Ericetum tetralicis

syntaxon code	soil	vege-tation type	seepage quality	seepage quantity	MPLS	pH	N availa-bility	syntaxon
11AA02A	***PN*** *SP*	HEA	0	1	62.8	3.89	4.73	Ericetum tetralicis sphagnetosum
11AA02B	***SP***	HEA	0	1	100.9	4.05	4.82	Ericetum tetralicis vaccinietosum
11AA02C	*PN* ***SP***	HEA	0	0	68.5	3.76	4.80	Ericetum tetralicis typicum
11AA02D	***SP***	HEA	0	0	108.3	3.86	4.82	Ericetum tetralicis cladonietosum
11AA02E	***SP*** SR	HEA	0	0	79.8	4.12	4.77	Ericetum tetralicis orchietosum
11AA03	***SP***	HEA	0	0	84.5	4.33	4.97	Empetro-Ericetum
11BA01	***PN*** SP	HEA	0	1	59.3	3.95	4.70	Erico-Sphagnetum magellanici
11BA02	***PN***	HEA	0	1	69.9	4.74	5.08	Sphagno palustris-Ericetum
12BA01	*CC* *SC*	GRP	5	1	90.4	7.00	6.22	Ranunculo-Alopecuretum geniculati
12BA03	CC *SR*	GRP	4	1	97.9	7.00	6.16	Trifolio fragiferi-Agrostietum stoloniferae
13AA01	*CC*	GRP	0	0	163.0	7.00	5.65	Cerastietum pumili
14AA01	***SP***	GRP	0	0	174.2	4.26	5.45	Spergulo-Corynephoretum
14AA02	***SP***	GRP	0	0	158.3	4.95	5.68	Violo-Corynephoretum
14BA01	*SP*	GRP	0	0	155.2	4.65	5.77	Ornithopodo-Corynephoretum
14BB01	***SP***	GRP	0	0	144.7	4.88	5.85	Festuco-Thymetum serpylli
14BB02	***SP***	GRP	0	0	150.5	5.16	5.88	Festuco-Galietum veri
14BC01	*SC*	GRP	0	0	159.5	7.00	5.75	Sedo-Thymetum pulegioidis
14BC02	CC ***SC***	GRP	5	1	148.3	7.00	6.03	Medicagini-Avenetum pubescentis
14CA01	***SC***	GRP	0	0	166.0	7.00	5.86	Phleo-Tortuletum ruraliformis
14CA02	***SC***	GRP	0	0	163.2	7.00	5.86	Sileno-Tortuletum ruraliformis
14CB01	***SC***	GRP	0	0	146.8	7.00	5.91	Taraxaco-Galietum veri
14CB02	***SC***	GRP	0	0	152.0	7.00	5.80	Anthyllido-Silenetum
15AA01	*CC*	GRP	0	0	155.4	7.00	5.72	Gentiano-Koelerietum
16AA01	*PN* *SP*	GRP	1	0.1	79.6	5.20	5.76	Cirsio dissecti-Molinietum
16AA01A	CN *SP*	GRP	1	0.1	83.5	5.25	5.69	Cirsio dissecti-Molinietum nardetosum
16AA01B	*PN* *SP*	GRP	1	0.1	67.5	4.98	5.75	Cirsio dissecti-Molinietum typicum
16AA01C	***PN***	GRP	1	0.1	59.3	5.35	5.83	Cirsio dissecti-Molinietum peucedanetosum
16AA01D	***SR***	GRP	1	0.1	74.9	5.41	5.73	Cirsio dissecti-Molinietum parnassietosum

syntaxon code	soil	vege-tation type	seepage quality	seepage quantity	MPLS	pH	N availa-bility	syntaxon
16AB01	LN *PN* *SP*	GRP	1	0.1	84.6	5.51	5.93	Crepido-Juncetum acutiflori
16AB02	CN *SC* SP SR	GRP	1	0.1	110.3	5.67	5.92	Rhinantho-Orchietum morionis
16AB04	CN ***PN***	GRP	5	1	73.0	5.48	6.05	Ranunculo-Senecionetum aquatici
16AB06	***PN*** ***SR***	GRP	5	1	82.8	5.83	6.06	Angelico-Cirsietum oleracei
16BA01	*CC* CN	GRP	5	1	94.3	7.00	6.14	Fritillario-Alopecuretum pratensis
16BB01	*CC* *SR*	GRP	0	0	128.9	7.00	6.15	Arrhenatheretum elatioris
16BC01	***CN*** *PN* *SR*	GRP	0	0	113.4	5.48	6.15	Lolio-Cynosuretum
16BC02	*CC*	GRP	0	0	144.0	7.00	5.95	Galio-Trifolietum
17AA01A	*CC*	GRP	0	0	133.9	7.00	6.03	Rubo-Origanetum typicum
17AA01B	***CC***	GRP	0	0	131.4	7.00	6.12	Rubo-Origanetum festucetosum arundinaceae
17AA02	***SC***	GRP	0	0	139.4	7.00	6.07	Polygonato-Lithospermetum
18AA01	*SP*	GRP	0	0	128.6	4.46	5.83	Hyperico pulchri-Melampyretum pratensis
18AA02	***SP*** SR	GRP	0	0	126.1	4.98	6.02	Hieracio-Holcetum mollis
19AA01	***SP***	GRP	0	0	131.0	4.31	5.68	Galio hercynici-Festucetum ovinae
19AA02	***SP***	GRP	1	0.1	93.1	4.35	5.62	Gentiano pneumonanthes-Nardetum
19AA03	***SP***	GRP	1	0.1	125.3	4.95	5.79	Botrychio-Polygaletum
19AA04	*SR*	GRP	0	0	142.0	5.40	5.81	Betonico-Brachypodietum
20AA01	***SP***	HEA	0	0	131.0	4.05	4.86	Genisto anglicae-Callunetum
20AB01	***SP***	HEA	0	0	148.1	4.28	4.86	Carici arenariae-Empetretum
20AB02	***SP***	HEA	0	0	145.4	4.99	5.04	Polypodio-Empetretum
20AB03	***SP***	HEA	0	0	128.7	4.36	4.95	Salici repentis-Empetretum
20AB04	**SC** *SP*	HEA	0	0	111.9	7.00	5.13	Pyrolo-Salicetum
22AB01	*SC*	GRP	4	1	112.1	7.00	6.31	Salsolo-Cakiletum maritimae
23AA01	*SC*	GRP	4	1	120.2	7.00	6.32	Honckenyo-Agropyretum juncei
23AB01	*SC*	GRP	0	0	139.8	7.00	6.15	Elymo-Ammophiletum
24AA01	*CC* *SC*	GRP	4	2	68.5	7.00	6.29	Spartinetum maritimae
24AA02	CC SC	GRP	4	2	62.8	7.00	6.28	Spartinetum townsendii
25AA01	***SC***	GRP	4	2	55.2	7.00	6.27	Salicornietum dolichostachyae

syntaxon code	soil	vege-tation type	seepage quality	seepage quantity	MPLS	pH	N availa-bility	syntaxon
25AA02	CC CN	GRP	4	2	72.7	7.00	6.27	Salicornietum brachystachyae
25AA03	*CC* *SC*	GRP	4	1	76.4	7.00	6.27	Suaedetum maritimae
26AA01	***CC*** CN *SC*	GRP	4	1	80.5	7.00	6.23	Puccinellietum maritimae
26AA02	***SC***	GRP	4	1	82.3	7.00	6.20	Plantagini-Limonietum
26AA03	*CC*	GRP	4	1	82.7	7.00	6.27	Halimionetum portulacoides
26AB01	*CC* CN *SC*	GRP	4	1	85.5	7.00	6.25	Puccinellietum distantis
26AC01	*CC* CN ***SC***	GRP	4	1	94.6	7.00	6.13	Juncetum gerardi
26AC02	CC *SC*	GRP	4	1	100.7	7.00	6.17	Armerio-Festucetum litoralis
26AC06	CC *SC*	GRP	4	1	108.3	7.00	6.28	Atriplici-Elytrigietum pungentis
26AC07	CC CN ***SC***	GRP	3	1	88.0	7.00	6.12	Oenantho lachenalii-Juncetum maritimi
27AA02	***SC***	GRP	1	0.1	96.9	7.00	6.13	Centaurio-Saginetum
28AA01	***SP***	GRP	1	0.1	77.0	4.90	5.95	Cicendietum filiformis
28AA02	***SR***	GRP	1	0.1	79.9	5.51	6.14	Isolepido-Stellarietum uliginosae
29AA02	CC ***CN*** ***PN*** *SC*	GRP	3	1	55.2	7.00	6.29	Rumicetum maritimi
29AA04	CC *SR*	GRP	5	3	70.2	7.00	6.22	Eleocharito acicularis-Limoselletum
30AA01	*CC*	GRP	0	0	131.0	7.00	6.14	Kickxietum spuriae
30AA02	*CC*	GRP	0	0	127.6	7.00	6.21	Papaveri-Melandrietum noctiflori
30AB01	***CC***	GRP	0	0	125.3	7.00	6.24	Veronico-Lamietum hybridi
30AB03	CN SR	GRP	0	0	122.3	6.11	6.27	Chenopodio-Oxalidetum fontanae
30BA01	*SP* SR	GRP	0	0	129.4	4.48	6.11	Scleranthо annui-Arnoseridetum
30BA02	*CN*	GRP	0	0	135.4	5.43	6.13	Papaveretum argemones
30BB01	*CN* *SR*	GRP	0	0	135.1	5.45	6.18	Spergulo arvensis-Chrysanthemetum
31AA01	***SC***	GRP	0	0	143.0	7.00	6.20	Bromo-Corispermetum
31AA02	*CC* *SC*	GRP	0	0	139.6	7.00	6.22	Erigeronto-Lactucetum
31AB03	***CC*** *SC*	GRP	0	0	128.5	7.00	6.29	Balloto-Arctietum
31BA01	*SC*	GRP	0	0	149.2	7.00	6.15	Echio-Verbascetum
31CA02	***CC*** *SC*	GRP	5	1	140.6	7.00	6.12	Bromo inermis-Eryngietum campestris
32AA01	*CC* *PN* *SC*	GRP	5	2	69.3	7.00	6.20	Valeriano-Filipenduletum

syntaxon code	soil	vege-tation type	seepage quality	seepage quantity	MPLS	pH	N availa-bility	syntaxon
32BA01	*CC* CN	GRP	5	1	71.9	7.00	6.29	Valeriano-Senecionetum fluviatilis
32BA02A	*CC* CN ***PN***	GRP	3	1	68.5	7.00	6.28	Soncho-Epilobietum typicum
32BA03	CC ***CN*** *SR*	GRP	3	1	91.2	7.00	6.25	Oenantho-Althaeetum
35AA01	*PN* ***SP*** SR	DEC	0	0	115.9	4.33	7.26	Rubetum grati
35AA02	*SP* SR	DEC	0	0	116.8	4.95	7.33	Rubetum silvatici
36AA01	*PN* SP	DEC	1	0.1	64.2	4.86	7.10	Salicetum auritae
36AA02	*CC* *PN*	DEC	5	2	62.8	7.00	7.33	Salicetum cinereae
37AB01	***CC*** CN	DEC	5	1	117.4	7.00	7.45	Pruno-Crataegetum
37AB02	*SP* SR	DEC	0	0	129.3	5.01	7.21	Roso-Juniperetum
37AC01	***SC***	DEC	0	0	131.0	7.00	7.42	Hippophao-Sambucetum
37AC02	***SC***	DEC	0	0	134.1	7.00	7.32	Hippophao-Ligustretum
37AC03	***SC***	DEC	0	0	132.7	7.00	7.32	Rhamno-Crataegetum
37AC04	*CC*	DEC	0	0	130.4	7.00	7.36	Pruno spinosae-Ligustretum
37AC05	*CC*	DEC	0	0	125.9	7.00	7.36	Orchio-Cornetum
38AA01	***CC*** *SC*	DEC	5	1	97.6	7.00	7.43	Artemisio-Salicetum albae
38AA02	***CC*** CN	DEC	5	1	71.9	7.00	7.42	Irido-Salicetum albae
38AA03	*CC* CN	DEC	5	1	79.8	7.00	7.47	Cardamino amarae-Salicetum albae
39AA01	CN ***PN***	DEC	1	0.1	66.8	5.56	7.27	Thelypterido-Alnetum
39AA02	*PN* SR	DEC	1	0.1	71.3	5.63	7.32	Carici elongatae-Alnetum
40AA01	***PN*** SP	DEC	0	0	106.2	4.18	6.99	Erico-Betuletum pubescentis
40AA02	CN ***PN***	DEC	1	0.1	72.5	4.99	7.18	Carici curtae-Betuletum pubescentis
41AA01	*SP*	PIN	0	0	137.9	4.43	6.74	Dicrano-Juniperetum
41AA02	***SP***	PIN	0	0	134.3	4.22	6.59	Cladonio-Pinetum sylvestris
41AA03	***SP***	PIN	0	0	126.5	4.31	6.77	Leucobryo-Pinetum
42AA01	***SP***	DEC	0	0	131.0	4.29	7.03	Betulo-Quercetum roboris
42AA02	***SP*** ***SR***	DEC	0	0	117.4	4.57	7.18	Fago-Quercetum
42AA03	***SP*** SR	DEC	0	0	128.2	4.37	7.23	Deschampsio-Fagetum
42AB01	*SP*	DEC	0	0	121.9	5.42	7.20	Luzulo luzuloidis-Fagetum

syntaxon code	soil	vege-tation type	seepage quality	seepage quantity	MPLS	pH	N availa-bility	syntaxon
43AA01	SC	DEC	5	1	116.5	7.00	7.44	Violo odoratae-Ulmetum
43AA02	***CC*** CN	DEC	5	1	114.6	7.00	7.43	Fraxino-Ulmetum
43AA03	***SC***	DEC	0	0	117.0	7.00	7.31	Crataego-Betuletum pubescentis
43AA05	CN ***SR***	DEC	5	1	103.6	5.87	7.36	Pruno-Fraxinetum
43AB01	*CC* *CN*	DEC	0	0	117.4	7.00	7.36	Stellario-Carpinetum
43RG03	*CC* CN *PN*	DEC	5	1	94.6	7.00	7.40	RG Urtica dioica [Circaeo-Alnenion]

Appendix 2 critical loads in kg N ha^{-1}.y^{-1} per vegetation - soil combination.

Soil type codes are explained in Table 3. Values in brackets should be considered as less reliable.

syntaxon code	soil type	critical load	syntaxon	syntaxon (Dutch name)
06AC03	PN	22.0	Eleocharitetum multicaulis	Associatie van Veelstengelige waterbies
06AC03	SP	21.1	Eleocharitetum multicaulis	Associatie van Veelstengelige waterbies
06AC04	SP	12.2	Samolo-Littorelletum	Associatie van Waterpunge en Oeverkruid
08AB01	CC	23.5	Rorippo-Oenanthetum aquaticae	Watertorkruid-associatie
08BA02	PN	29.7	Cicuto-Caricetum pseudocyperi	Associatie van Waterscheerling en Hoge cyperzegge
08BB03A	CC	23.2	Alismato-Scirpetum scirpetosum triquetri	Ass. van Heen en Grote waterweegbree; subass. met Driekantige bies
08BB03A	CN	22.4	Alismato-Scirpetum scirpetosum triquetri	Ass. van Heen en Grote waterweegbree; subass. met Driekantige bies
08BB03A	PN	22.2	Alismato-Scirpetum scirpetosum triquetri	Ass. van Heen en Grote waterweegbree; subass. met Driekantige bies
08BB03A	SR	22.3	Alismato-Scirpetum scirpetosum triquetri	Ass. van Heen en Grote waterweegbree; subass. met Driekantige bies
08BB04	CC	25.7	Typho-Phragmitetum	Riet-associatie
08BB04	CN	24.2	Typho-Phragmitetum	Riet-associatie
08BB04	PN	21.1	Typho-Phragmitetum	Riet-associatie
08BC02	CC	25.9	Caricetum gracilis	Associatie van Scherpe zegge
08BC02	CN	24.2	Caricetum gracilis	Associatie van Scherpe zegge
08BC02	PN	20.5	Caricetum gracilis	Associatie van Scherpe zegge
09AA01	PN	26.9	Caricetum trinervi-nigrae	Associatie van Drienervige en Zwarte zegge
09AA01	SP	11.8	Caricetum trinervi-nigrae	Associatie van Drienervige en Zwarte zegge
09AA02	PN	7.2	Pallavicinio-Sphagnetum	Veenmosrietland
09AA03	PN	18.1	Carici curtae-Agrostietum caninae	Associatie van Moerasstruisgras en Zompzegge
09AA03	SR	17.5	Carici curtae-Agrostietum caninae	Associatie van Moerasstruisgras en Zompzegge
09BA01	PN	15.8	Scorpidio-Caricetum diandrae	Associatie van Schorpioenmos en Ronde zegge
09BA03	SC	17.7	Parnassio-Juncetum atricapilli	Associatie van Duinrus en Parnassia
09BA04	SC	17.8	Junco baltici-Schoenetum nigricantis	Knopbies-associatie
09BA05	CC	22.0	Equiseto variegati-Salicetum repentis	Associatie van Bonte paardestaart en Moeraswespenorchis
09BA05	CN	21.7	Equiseto variegati-Salicetum repentis	Associatie van Bonte paardestaart en Moeraswespenorchis
10AA01	PN	33.1	Sphagnetum cuspidato-obesi	Waterveenmos-associatie
10AA01	SP	31.1	Sphagnetum cuspidato-obesi	Waterveenmos-associatie

syntaxon code	soil type	critical load	syntaxon	syntaxon (Dutch name)
10AA02	PN	28.9	Sphagno-Rhynchosporetum	Associatie van Veenmos en Snavelbies
10AA02	SP	(1.8)	Sphagno-Rhynchosporetum	Associatie van Veenmos en Snavelbies
10AA03	PN	30.3	Caricetum limosae	Veenbloembies-associatie
10AA03	SP	30.8	Caricetum limosae	Veenbloembies-associatie
11AA01	SP	(8.7)	Lycopodio-Rhynchosporetum	Associatie van Moeraswolfsklauw en Snavelbies
11AA02	PN	(29.2)	Ericetum tetralicis	Associatie van Gewone dophei
11AA02	SP	(14.1)	Ericetum tetralicis	Associatie van Gewone dophei
11AA02A	PN	27.2	Ericetum tetralicis sphagnetosum	Ass. van Gewone dophei; subass. met Veenmos
11AA02A	SP	(15.0)	Ericetum tetralicis sphagnetosum	Ass. van Gewone dophei; subass. met Veenmos
11AA02B	SP	(29.1)	Ericetum tetralicis vaccinietosum	Ass. van Gewone dophei; subass. met Bosbes
11AA02C	PN	28.0	Ericetum tetralicis typicum	Ass. van Gewone dophei; typische subass.
11AA02C	SP	26.0	Ericetum tetralicis typicum	Ass. van Gewone dophei; typische subass.
11AA02D	SP	14.9	Ericetum tetralicis cladonietosum	Ass. van Gewone dophei; subass. met korstmossen
11AA02E	SP	(2.0)	Ericetum tetralicis orchietosum	Ass. van Gewone dophei; subass. met Gevlekte orchis
11AA02E	SR	(28.2)	Ericetum tetralicis orchietosum	Ass. van Gewone dophei; subass. met Gevlekte orchis
11AA03	SP	30.6	Empetro-Ericetum	Associatie van Kraaihei en Gewone dophei
11BA01	PN	26.4	Erico-Sphagnetum magellanici	Associatie van Gewone dophei en Veenmos
11BA01	SP	(8.1)	Erico-Sphagnetum magellanici	Associatie van Gewone dophei en Veenmos
11BA02	PN	32.9	Sphagno palustris-Ericetum	Moerasheide
12BA01	CC	22.4	Ranunculo-Alopecuretum geniculati	Associatie van Geknikte vossestaart
12BA01	SC	22.2	Ranunculo-Alopecuretum geniculati	Associatie van Geknikte vossestaart
12BA03	CC	21.4	Trifolio fragiferi-Agrostietum stoloniferae	Associatie van Aardbeiklaver en Fioringras
12BA03	SR	21.4	Trifolio fragiferi-Agrostietum stoloniferae	Associatie van Aardbeiklaver en Fioringras
13AA01	CC	20.1	Cerastietum pumili	Associatie van Tengere veldmuur
14AA01	SP	10.4	Spergulo-Corynephoretum	Associatie van Buntgras en Heidespurrie
14AA02	SP	11.2	Violo-Corynephoretum	Duin-Buntgras-associatie
14BA01	SP	14.0	Ornithopodo-Corynephoretum	Vogelpootjes-associatie
14BB01	SP	14.7	Festuco-Thymetum serpylli	Associatie van Schapegras en Tijm
14BB02	SP	14.1	Festuco-Galietum veri	Duin-Struisgras-associatie

syntaxon code	soil type	critical load	syntaxon	syntaxon (Dutch name)
14BC01	SC	15.5	Sedo-Thymetum pulegioidis	Associatie van Vetkruid en Tijm
14BC02	CC	19.4	Medicagini-Avenetum pubescentis	Associatie van Sikkelklaver en Zachte haver
14BC02	SC	19.7	Medicagini-Avenetum pubescentis	Associatie van Sikkelklaver en Zachte haver
14CA01	SC	17.2	Phleo-Tortuletum ruraliformis	Duinsterretjes-associatie
14CA02	SC	16.9	Sileno-Tortuletum ruraliformis	Kegelsilene-associatie
14CB01	SC	17.1	Taraxaco-Galietum veri	Duin-Paardebloem-associatie
14CB02	SC	16.2	Anthyllido-Silenetum	Associatie van Wondklaver en Nachtsilene
15AA01	CC	20.6	Gentiano-Koelerietum	Kalkgrasland
16AA01	PN	(1.8)	Cirsio dissecti-Molinietum	Blauwgrasland
16AA01	SP	10.2	Cirsio dissecti-Molinietum	Blauwgrasland
16AA01A	CN	17.2	Cirsio dissecti-Molinietum nardetosum	Blauwgrasland; subass. met Borstelgras
16AA01A	SP	9.8	Cirsio dissecti-Molinietum nardetosum	Blauwgrasland; subass. met Borstelgras
16AA01B	PN	5.5	Cirsio dissecti-Molinietum typicum	Blauwgrasland; typische subass.
16AA01B	SP	9.7	Cirsio dissecti-Molinietum typicum	Blauwgrasland; typische subass.
16AA01C	PN	(1.8)	Cirsio dissecti-Molinietum peucedanetosum	Blauwgrasland; subass. met Melkeppe
16AA01D	SR	9.5	Cirsio dissecti-Molinietum parnassietosum	Blauwgrasland; subass. met Parnassia
16AB01	LN	13.2	Crepido-Juncetum acutiflori	Veldrus-associatie
16AB01	PN	(1.8)	Crepido-Juncetum acutiflori	Veldrus-associatie
16AB01	SP	11.4	Crepido-Juncetum acutiflori	Veldrus-associatie
16AB02	CN	17.6	Rhinantho-Orchietum morionis	Associatie van Harlekijn en Ratelaar
16AB02	SC	18.0	Rhinantho-Orchietum morionis	Associatie van Harlekijn en Ratelaar
16AB02	SP	11.1	Rhinantho-Orchietum morionis	Associatie van Harlekijn en Ratelaar
16AB02	SR	11.3	Rhinantho-Orchietum morionis	Associatie van Harlekijn en Ratelaar
16AB04	CN	23.7	Ranunculo-Senecionetum aquatici	Associatie van Boterbloemen en Waterkruiskruid
16AB04	PN	19.3	Ranunculo-Senecionetum aquatici	Associatie van Boterbloemen en Waterkruiskruid
16AB06	PN	19.9	Angelico-Cirsietum oleracei	Associatie van Gewone engelwortel en Moeraszegge
16AB06	SR	19.8	Angelico-Cirsietum oleracei	Associatie van Gewone engelwortel en Moeraszegge
16BA01	CC	21.5	Fritillario-Alopecuretum pratensis	Kievitsbloem-associatie
16BA01	CN	21.4	Fritillario-Alopecuretum pratensis	Kievitsbloem-associatie

syntaxon code	soil type	critical load	syntaxon	syntaxon (Dutch name)
16BB01	CC	23.7	Arrhenatheretum elatioris	Glanshaver-associatie
16BB01	SR	15.0	Arrhenatheretum elatioris	Glanshaver-associatie
16BC01	CN	21.1	Lolio-Cynosuretum	Kamgrasweide
16BC01	PN	18.0	Lolio-Cynosuretum	Kamgrasweide
16BC01	SR	17.6	Lolio-Cynosuretum	Kamgrasweide
16BC02	CC	21.6	Galio-Trifolietum	Associatie van Ruige weegbree en Aarddistel
17AA01A	CC	22.8	Rubo-Origanetum typicum	Ass. van Dauwbraam en Marjolein; typische subass.
17AA01B	CC	23.4	Rubo-Origanetum festucetosum arundinaceae	Ass. van Dauwbraam en Marjolein; subass. met Rietzwenkgras
17AA02	SC	19.7	Polygonato-Lithospermetum	Associatie van Parelzaad en Salomonszegel
18AA01	SP	15.5	Hyperico pulchri-Melampyretum pratensis	Associatie van Hengel en Gladde witbol
18AA02	SP	17.1	Hieracio-Holcetum mollis	Associatie van Boshavikskruid en Gladde witbol
18AA02	SR	16.9	Hieracio-Holcetum mollis	Associatie van Boshavikskruid en Gladde witbol
19AA01	SP	13.7	Galio hercynici-Festucetum ovinae	Associatie van Liggend walstro en Schapegras
19AA02	SP	9.6	Gentiano pneumonanthes-Nardetum	Associatie van Klokjesgentiaan en Borstelgras
19AA03	SP	10.8	Botrychio-Polygaletum	Associatie van Maanvaren en Vleugeltjesbloem
19AA04	SR	12.2	Betonico-Brachypodietum	Associatie van Betonie en Gevinde kortsteel
20AA01	SP	4.3	Genisto anglicae-Callunetum	Associatie van Struikhei en Stekelbrem
20AB01	SP	29.2	Carici arenariae-Empetretum	Associatie van Zandzegge en Kraaihei
20AB02	SP	30.7	Polypodio-Empetretum	Associatie van Eikvaren en Kraaihei
20AB03	SP	30.2	Salici repentis-Empetretum	Associatie van Kruipwilg en Kraaihei
20AB04	SC	33.3	Pyrolo-Salicetum	Associatie van Wintergroen en Kruipwilg
20AB04	SP	31.2	Pyrolo-Salicetum	Associatie van Wintergroen en Kruipwilg
22AB01	SC	23.6	Salsolo-Cakiletum maritimae	Associatie van Loogkruid en Zeeraket
23AA01	SC	23.6	Honckenyo-Agropyretum juncei	Associatie van Zandhaver en Biestarwegras
23AB01	SC	21.2	Elymo-Ammophiletum	Associatie van Zandhaver en Helm
24AA01	CC	23.2	Spartinetum maritimae	Associatie van Klein slijkgras
24AA01	SC	23.3	Spartinetum maritimae	Associatie van Klein slijkgras
24AA02	CC	23.1	Spartinetum townsendii	Associatie van Engels slijkgras
24AA02	SC	23.1	Spartinetum townsendii	Associatie van Engels slijkgras

syntaxon code	soil type	critical load	syntaxon	syntaxon (Dutch name)
25AA01	SC	23.0	Salicornietum dolichostachyae	Associatie van Langarige zeekraal
25AA02	CC	22.8	Salicornietum brachystachyae	Associatie van Kortarige zeekraal
25AA02	CN	22.5	Salicornietum brachystachyae	Associatie van Kortarige zeekraal
25AA03	CC	22.9	Suaedetum maritimae	Schorrekruid-associatie
25AA03	SC	22.9	Suaedetum maritimae	Schorrekruid-associatie
26AA01	CC	22.3	Puccinellietum maritimae	Associatie van Gewoon kweldergras
26AA01	CN	21.9	Puccinellietum maritimae	Associatie van Gewoon kweldergras
26AA01	SC	22.2	Puccinellietum maritimae	Associatie van Gewoon kweldergras
26AA02	SC	22.0	Plantagini-Limonietum	Associatie van Zeeweegbree en Lamsoor
26AA03	CC	22.7	Halimionetum portulacoides	Zoutmelde-associatie
26AB01	CC	22.8	Puccinellietum distantis	Associatie van Stomp kweldergras
26AB01	CN	21.7	Puccinellietum distantis	Associatie van Stomp kweldergras
26AB01	SC	22.5	Puccinellietum distantis	Associatie van Stomp kweldergras
26AC01	CC	21.0	Juncetum gerardi	Associatie van Zilte rus
26AC01	CN	20.9	Juncetum gerardi	Associatie van Zilte rus
26AC01	SC	21.0	Juncetum gerardi	Associatie van Zilte rus
26AC02	CC	21.5	Armerio-Festucetum litoralis	Associatie van Engels gras en Rood zwenkgras
26AC02	SC	21.5	Armerio-Festucetum litoralis	Associatie van Engels gras en Rood zwenkgras
26AC06	CC	23.0	Atriplici-Elytrigietum pungentis	Associatie van Spiesmelde en Strandkweek
26AC06	SC	23.1	Atriplici-Elytrigietum pungentis	Associatie van Spiesmelde en Strandkweek
26AC07	CC	25.8	Oenantho lachenalii-Juncetum maritimi	Associatie van Zeerus en Weidetorkruid
26AC07	CN	24.6	Oenantho lachenalii-Juncetum maritimi	Associatie van Zeerus en Weidetorkruid
26AC07	SC	20.9	Oenantho lachenalii-Juncetum maritimi	Associatie van Zeerus en Weidetorkruid
27AA02	SC	20.8	Centaurio-Saginetum	Associatie van Strandduizendguldenkruid en Krielparnassia
28AA01	SP	10.9	Cicendietum filiformis	Draadgentiaan-associatie
28AA02	SR	15.1	Isolepido-Stellarietum uliginosae	Associatie van Borstelbies en Moerasmuur
29AA02	CC	31.3	Rumicetum maritimi	Associatie van Goudzuring en Moerasandijvie
29AA02	CN	30.6	Rumicetum maritimi	Associatie van Goudzuring en Moerasandijvie
29AA02	PN	22.5	Rumicetum maritimi	Associatie van Goudzuring en Moerasandijvie

syntaxon code	soil type	critical load	syntaxon	syntaxon (Dutch name)
29AA02	SC	23.3	Rumicetum maritimi	Associatie van Goudzuring en Moerasandijvie
29AA04	CC	22.1	Eleocharito acicularis-Limoselletum	Slijkgroen-associatie
29AA04	SR	21.8	Eleocharito acicularis-Limoselletum	Slijkgroen-associatie
30AA01	CC	23.4	Kickxietum spuriae	Stoppelleeuwebek-associatie
30AA02	CC	24.0	Papaveri-Melandrietum noctiflori	Nachtkoekoeksbloem-associatie
30AB01	CC	24.4	Veronico-Lamietum hybridi	Associatie van Grote ereprijs en Witte krodde
30AB03	CN	22.3	Chenopodio-Oxalidetum fontanae	Associatie van Korrelganzevoet en Stijve klaverzuring
30AB03	SR	17.5	Chenopodio-Oxalidetum fontanae	Associatie van Korrelganzevoet en Stijve klaverzuring
30BA01	SP	19.7	Sclerantho annui-Arnoseridetum	Korensla-associatie
30BA01	SR	19.8	Sclerantho annui-Arnoseridetum	Korensla-associatie
30BA02	CN	21.2	Papaveretum argemones	Associatie van Ruige klaproos
30BB01	CN	21.8	Spergulo arvensis-Chrysanthemetum	Associatie van Gele ganzebloem
30BB01	SR	17.6	Spergulo arvensis-Chrysanthemetum	Associatie van Gele ganzebloem
31AA01	SC	22.0	Bromo-Corispermetum	Vlieszaad-associatie
31AA02	CC	22.9	Erigeronto-Lactucetum	Associatie van Raketten en Kompassla
31AA02	SC	22.0	Erigeronto-Lactucetum	Associatie van Raketten en Kompassla
31AB03	CC	24.5	Balloto-Arctietum	Associatie van Ballote en andere Netels
31AB03	SC	23.3	Balloto-Arctietum	Associatie van Ballote en andere Netels
31BA01	SC	21.0	Echio-Verbascetum	Slangekruid-associatie
31CA02	CC	20.8	Bromo inermis-Eryngietum campestris	Kweekdravik-associatie
31CA02	SC	21.0	Bromo inermis-Eryngietum campestris	Kweekdravik-associatie
32AA01	CC	21.8	Valeriano-Filipenduletum	Associatie van Moerasspirea en Echte Valeriaan
32AA01	PN	21.7	Valeriano-Filipenduletum	Associatie van Moerasspirea en Echte Valeriaan
32AA01	SC	22.0	Valeriano-Filipenduletum	Associatie van Moerasspirea en Echte Valeriaan
32BA01	CC	25.9	Valeriano-Senecionetum fluviatilis	Rivierkruiskruid-associatie
32BA01	CN	25.4	Valeriano-Senecionetum fluviatilis	Rivierkruiskruid-associatie
32BA02A	CC	29.2	Soncho-Epilobietum typicum	Moerasmelkdistel-ass.; typische subass.
32BA02A	CN	28.7	Soncho-Epilobietum typicum	Moerasmelkdistel-ass.; typische subass.
32BA02A	PN	22.9	Soncho-Epilobietum typicum	Moerasmelkdistel-ass.; typische subass.

syntaxon code	soil type	critical load	syntaxon	syntaxon (Dutch name)
32BA03	CC	25.6	Oenantho-Althaeetum	Associatie van Strandkweek en Echte heemst
32BA03	CN	25.6	Oenantho-Althaeetum	Associatie van Strandkweek en Echte heemst
32BA03	SR	21.9	Oenantho-Althaeetum	Associatie van Strandkweek en Echte heemst
35AA01	PN	33.4	Rubetum grati	Associatie van Bronskleurige bosbraam
35AA01	SP	(29.5)	Rubetum grati	Associatie van Bronskleurige bosbraam
35AA01	SR	29.4	Rubetum grati	Associatie van Bronskleurige bosbraam
35AA02	SP	30.2	Rubetum silvatici	Associatie van Witte bosbraam
35AA02	SR	29.1	Rubetum silvatici	Associatie van Witte bosbraam
36AA01	PN	36.7	Salicetum auritae	Associatie van Geoorde wilg
36AA01	SP	(28.7)	Salicetum auritae	Associatie van Geoorde wilg
36AA02	CC	38.8	Salicetum cinereae	Associatie van Grauwe wilg
36AA02	PN	22.4	Salicetum cinereae	Associatie van Grauwe wilg
37AB01	CC	32.1	Pruno-Crataegetum	Associatie van Sleedoorn en Eenstijlige meidoorn
37AB01	CN	23.7	Pruno-Crataegetum	Associatie van Sleedoorn en Eenstijlige meidoorn
37AB02	SP	28.5	Roso-Juniperetum	Associatie van Hondsroos en Jeneverbes
37AB02	SR	27.4	Roso-Juniperetum	Associatie van Hondsroos en Jeneverbes
37AC01	SC	29.0	Hippophao-Sambucetum	Associatie van Duindoorn en Vlier
37AC02	SC	28.0	Hippophao-Ligustretum	Associatie van Duindoorn en Liguster
37AC03	SC	27.9	Rhamno-Crataegetum	Associatie van Wegedoorn en Eenstijlige meidoorn
37AC04	CC	36.5	Pruno spinosae-Ligustretum	Associatie van rozen en Liguster
37AC05	CC	37.1	Orchio-Cornetum	Associatie van Hazelaar en Purperorchis
38AA01	CC	35.1	Artemisio-Salicetum albae	Bijvoet-ooibos
38AA01	SC	28.9	Artemisio-Salicetum albae	Bijvoet-ooibos
38AA02	CC	40.6	Irido-Salicetum albae	Gele lis-ooibos
38AA02	CN	30.0	Irido-Salicetum albae	Gele lis-ooibos
38AA03	CC	39.1	Cardamino amarae-Salicetum albae	Bittere veldkers-ooibos
38AA03	CN	29.0	Cardamino amarae-Salicetum albae	Bittere veldkers-ooibos
39AA01	CN	28.5	Thelypterido-Alnetum	Moerasvaren-Elzenbroek
39AA01	PN	36.5	Thelypterido-Alnetum	Moerasvaren-Elzenbroek

syntaxon code	soil type	critical load	syntaxon	syntaxon (Dutch name)
39AA02	PN	36.4	Carici elongatae-Alnetum	Elzenzegge-Elzenbroek
39AA02	SR	30.7	Carici elongatae-Alnetum	Elzenzegge-Elzenbroek
40AA01	PN	32.4	Erico-Betuletum pubescentis	Dophei-Berkenbroek
40AA01	SP	15.8	Erico-Betuletum pubescentis	Dophei-Berkenbroek
40AA02	CN	26.9	Carici curtae-Betuletum pubescentis	Zompzegge-Berkenbroek
40AA02	PN	34.8	Carici curtae-Betuletum pubescentis	Zompzegge-Berkenbroek
41AA01	SP	33.0	Dicrano-Juniperetum	Gaffeltandmos-Jeneverbestruweel
41AA02	SP	8.5	Cladonio-Pinetum sylvestris	Korstmossen-Dennenbos
41AA03	SP	(33.8)	Leucobryo-Pinetum	Kussentjesmos-Dennenbos
42AA01	SP	(10.5)	Betulo-Quercetum roboris	Berken-Eikenbos
42AA02	SP	29.1	Fago-Quercetum	Beuken-Zomereikenbos
42AA02	SR	28.1	Fago-Quercetum	Beuken-Zomereikenbos
42AA03	SP	29.4	Deschampsio-Fagetum	Bochtige smele-Beukenbos
42AA03	SR	28.2	Deschampsio-Fagetum	Bochtige smele-Beukenbos
42AB01	SP	28.0	Luzulo luzuloidis-Fagetum	Veldbies-Beukenbos
43AA01	SC	29.1	Violo odoratae-Ulmetum	Abelen-Iepenbos
43AA02	CC	32.3	Fraxino-Ulmetum	Essen- Iepenbos
43AA02	CN	23.6	Fraxino-Ulmetum	Essen- Iepenbos
43AA03	SC	27.9	Crataego-Betuletum pubescentis	Meidoorn-Berkenbos
43AA05	CN	24.5	Pruno-Fraxinetum	Vogelkers-Essenbos
43AA05	SR	12.9	Pruno-Fraxinetum	Vogelkers-Essenbos
43AB01	CC	37.8	Stellario-Carpinetum	Eiken-Haagbeukenbos
43AB01	CN	22.7	Stellario-Carpinetum	Eiken-Haagbeukenbos
43RG03	CC	35.7	RG Urtica dioica [Circaeo-Alnenion]	Rompgemeenschap van Grote brandnetel
43RG03	CN	26.1	RG Urtica dioica [Circaeo-Alnenion]	Rompgemeenschap van Grote brandnetel
43RG03	PN	30.5	RG Urtica dioica [Circaeo-Alnenion]	Rompgemeenschap van Grote brandnetel

Appendix 3 uncertainty in critical load, with and without USV.

Figures in the 'uncertainty analysis' columns are means and standard errors of critical loads resulting from 100 possible input values of SMART^{-1}. The critical loads from Appendix 2 are given for comparison.

syntaxon code	syntaxon	soiltype (see Table 5)	critical load in Appendix 2 (kg N ha^{-1}.y^{-1})	critical load from uncertainty analysis (kg N ha^{-1}.y^{-1})			
				without USV		with USV	
				mean	s.e.	mean	s.e.
06AC03	Eleocharitetum multicaulis	PN	22.0	22.2	0.6	21.1	16.6
06AC03	Eleocharitetum multicaulis	SP	21.1	21.1	0.6	20.4	16.5
06AC04	Samolo-Littorelletum	SP	12.2	11.8	0.6	15.9	10.7
08AB01	Rorippo-Oenanthetum aquaticae	CC	23.5	23.3	0.5	27.4	15.0
08BA02	Cicuto-Caricetum pseudocyperi	PN	29.7	29.9	0.3	17.8	10.8
08BB03A	Alismato-Scirpetum scirpetosum triquetri	CC	23.2	23.3	0.6	27.5	15.3
08BB03A	Alismato-Scirpetum scirpetosum triquetri	CN	22.4	22.3	0.6	26.4	15.7
08BB03A	Alismato-Scirpetum scirpetosum triquetri	PN	22.2	22.2	0.6	24.7	17.3
08BB03A	Alismato-Scirpetum scirpetosum triquetri	SR	22.3	22.1	0.6	23.8	17.5
08BB04	Typho-Phragmitetum	CC	25.7	25.8	0.4	26.9	14.8
08BB04	Typho-Phragmitetum	CN	24.2	24.5	0.6	25.9	15.2
08BB04	Typho-Phragmitetum	PN	21.1	20.9	0.6	23.6	16.8
08BC02	Caricetum gracilis	CC	25.9	25.9	0.4	26.6	14.7
08BC02	Caricetum gracilis	CN	24.2	24.7	0.6	25.6	15.1
08BC02	Caricetum gracilis	PN	20.5	20.5	0.5	23.3	16.8
09AA01	Caricetum trinervi-nigrae	PN	26.9	26.4	1.5	14.5	10.1
09AA01	Caricetum trinervi-nigrae	SP	11.8	11.3	0.7	15.3	10.5
09AA02	Pallavicinio-Sphagnetum	PN	7.2	6.9	1.0	13.9	10.2
09AA03	Carici curtae-Agrostietum caninae	PN	18.1	17.1	2.1	14.4	10.8
09AA03	Carici curtae-Agrostietum caninae	SR	17.5	17.1	1.1	16.7	10.5
09BA01	Scorpidio-Caricetum diandrae	PN	15.8	15.7	0.5	19.9	15.7
09BA03	Parnassio-Juncetum atricapilli	SC	17.7	17.4	0.5	22.1	14.7
09BA04	Junco baltici-Schoenetum nigricantis	SC	17.8	17.6	0.4	22.3	14.7

syntaxon code	syntaxon	soiltype (see Table 5)	critical load in Appendix 2 (kg N ha^{-1}.y^{-1})	critical load from uncertainty analysis (kg N ha^{-1}.y^{-1})			
				without USV		with USV	
				mean	s.e.	mean	s.e.
09BA05	Equiseto variegati-Salicetum repentis	CC	22.0	22.2	0.3	25.6	13.0
09BA05	Equiseto variegati-Salicetum repentis	CN	21.7	21.7	0.3	24.8	13.3
10AA01	Sphagnetum cuspidato-obesi	PN	33.1	33.1	0.8	32.8	18.8
10AA01	Sphagnetum cuspidato-obesi	SP	31.1	31.5	1.1	31.8	19.2
10AA02	Sphagno-Rhynchosporetum	PN	28.9	27.9	1.5	28.9	18.7
10AA02	Sphagno-Rhynchosporetum	SP	1.8	19.4	12.5	26.5	18.6
10AA03	Caricetum limosae	PN	30.3	29.9	1.3	30.3	18.5
10AA03	Caricetum limosae	SP	30.8	30.6	0.9	29.6	19.1
11AA01	Lycopodio-Rhynchosporetum	SP	8.7	9.5	5.3	27.4	17.5
11AA02	Ericetum tetralicis	PN	29.2	25.6	9.1	27.9	19.1
11AA02	Ericetum tetralicis	SP	14.1	14.1	5.0	27.2	17.7
11AA02A	Ericetum tetralicis sphagnetosum	PN	27.2	26.9	0.9	28.1	17.9
11AA02A	Ericetum tetralicis sphagnetosum	SP	15.0	14.7	5.0	27.3	17.5
11AA02B	Ericetum tetralicis vaccinietosum	SP	29.1	25.7	8.5	27.0	19.0
11AA02C	Ericetum tetralicis typicum	PN	28.0	27.7	0.9	28.8	17.8
11AA02C	Ericetum tetralicis typicum	SP	26.0	24.9	3.7	26.4	17.5
11AA02D	Ericetum tetralicis cladonietosum	SP	14.9	15.4	3.2	24.7	17.1
11AA02E	Ericetum tetralicis orchietosum	SP	2.0	13.8	12.7	25.0	18.2
11AA02E	Ericetum tetralicis orchietosum	SR	28.2	21.6	11.0	26.4	18.8
11AA03	Empetro-Ericetum	SP	30.6	30.5	0.9	28.6	19.1
11BA01	Erico-Sphagnetum magellanici	PN	26.4	26.4	0.8	27.7	18.3
11BA01	Erico-Sphagnetum magellanici	SP	8.1	9.2	5.1	26.3	17.4
11BA02	Sphagno palustris-Ericetum	PN	32.9	32.8	0.9	33.2	19.4
12BA01	Ranunculo-Alopecuretum geniculati	CC	22.4	22.7	0.3	27.9	14.2
12BA01	Ranunculo-Alopecuretum geniculati	SC	22.2	22.2	0.5	24.1	17.4
12BA03	Trifolio fragiferi-Agrostietum stoloniferae	CC	21.4	21.4	0.5	23.3	17.4

syntaxon code	syntaxon	soiltype (see Table 5)	critical load in Appendix 2 (kg N ha^{-1}.y^{-1})	critical load from uncertainty analysis (kg N ha^{-1}.y^{-1})			
				without USV		with USV	
				mean	s.e.	mean	s.e.
12BA03	Trifolio fragiferi-Agrostietum stoloniferae	SR	21.4	21.1	0.6	22.9	17.3
13AA01	Cerastietum pumili	CC	20.1	20.1	0.2	24.5	10.8
14AA01	Spergulo-Corynephoretum	SP	10.4	10.3	0.8	14.0	14.4
14AA02	Violo-Corynephoretum	SP	11.2	11.1	0.7	15.9	15.5
14BA01	Ornithopodo-Corynephoretum	SP	14.0	14.0	0.5	16.5	15.0
14BB01	Festuco-Thymetum serpylli	SP	14.7	14.5	0.5	18.0	16.1
14BB02	Festuco-Galietum veri	SP	14.1	14.1	0.5	18.2	16.2
14BC01	Sedo-Thymetum pulegioidis	SC	15.5	15.5	0.5	20.2	14.4
14BC02	Medicagini-Avenetum pubescentis	CC	19.4	19.6	0.4	24.1	14.9
14BC02	Medicagini-Avenetum pubescentis	SC	19.7	19.6	0.4	21.7	16.9
14CA01	Phleo-Tortuletum ruraliformis	SC	17.2	17.0	0.4	21.0	14.5
14CA02	Sileno-Tortuletum ruraliformis	SC	16.9	17.0	0.5	21.2	14.9
14CB01	Taraxaco-Galietum veri	SC	17.1	17.7	0.4	21.9	14.9
14CB02	Anthyllido-Silenetum	SC	16.2	16.2	0.4	20.8	14.5
15AA01	Gentiano-Koelerietum	CC	20.6	20.4	0.2	25.2	11.0
16AA01	Cirsio dissecti-Molinietum	PN	1.8	1.8	0.1	12.6	9.7
16AA01	Cirsio dissecti-Molinietum	SP	10.2	10.1	0.3	14.9	9.7
16AA01A	Cirsio dissecti-Molinietum nardetosum	CN	17.2	17.0	0.3	21.3	12.1
16AA01A	Cirsio dissecti-Molinietum nardetosum	SP	9.8	9.7	0.3	14.4	9.5
16AA01B	Cirsio dissecti-Molinietum typicum	PN	5.5	5.8	1.1	13.3	9.8
16AA01B	Cirsio dissecti-Molinietum typicum	SP	9.7	9.7	0.3	15.2	10.3
16AA01C	Cirsio dissecti-Molinietum peucedanetosum	PN	1.8	7.1	5.3	14.1	10.6
16AA01D	Cirsio dissecti-Molinietum parnassietosum	SR	9.5	9.5	0.4	11.8	10.3
16AB01	Crepido-Juncetum acutiflori	LN	13.2	13.2	0.4	17.2	15.1
16AB01	Crepido-Juncetum acutiflori	PN	1.8	2.5	1.7	13.0	9.0
16AB01	Crepido-Juncetum acutiflori	SP	11.4	11.2	0.3	15.8	9.8

syntaxon code	syntaxon	soiltype (see Table 5)	critical load in Appendix 2 (kg N ha^{-1}.y^{-1})	critical load from uncertainty analysis (kg N ha^{-1}.y^{-1})			
				without USV		with USV	
				mean	s.e.	mean	s.e.
16AB02	Rhinantho-Orchietum morionis	CN	17.6	17.4	0.4	22.2	11.6
16AB02	Rhinantho-Orchietum morionis	SC	18.0	17.8	0.4	22.4	14.7
16AB02	Rhinantho-Orchietum morionis	SP	11.1	11.2	0.2	15.4	9.3
16AB02	Rhinantho-Orchietum morionis	SR	11.3	11.4	0.4	7.9	8.7
16AB04	Ranunculo-Senecionetum aquatici	CN	23.7	24.0	0.5	26.1	13.5
16AB04	Ranunculo-Senecionetum aquatici	PN	19.3	19.3	0.4	23.0	15.7
16AB06	Angelico-Cirsietum oleracei	PN	19.9	19.6	0.8	23.9	15.3
16AB06	Angelico-Cirsietum oleracei	SR	19.8	19.5	0.5	21.2	16.8
16BA01	Fritillario-Alopecuretum pratensis	CC	21.5	21.7	0.3	27.1	14.0
16BA01	Fritillario-Alopecuretum pratensis	CN	21.4	21.4	0.3	26.4	14.1
16BB01	Arrhenatheretum elatioris	CC	23.7	24.0	0.4	29.3	12.5
16BB01	Arrhenatheretum elatioris	SR	15.0	14.9	0.6	21.5	17.1
16BC01	Lolio-Cynosuretum	CN	21.1	20.6	1.0	23.3	13.5
16BC01	Lolio-Cynosuretum	PN	18.0	18.0	0.5	24.8	16.4
16BC01	Lolio-Cynosuretum	SR	17.6	17.6	0.5	23.0	17.0
16BC02	Galio-Trifolietum	CC	21.6	22.0	0.3	27.2	11.8
17AA01A	Rubo-Origanetum typicum	CC	22.8	23.2	0.3	28.2	12.0
17AA01B	Rubo-Origanetum festucetosum arundinaceae	CC	23.4	23.7	0.3	29.0	12.3
17AA02	Polygonato-Lithospermetum	SC	19.7	19.9	0.5	23.6	15.4
18AA01	Hyperico pulchri-Melampyretum pratensis	SP	15.5	15.5	0.4	18.1	15.4
18AA02	Hieracio-Holcetum mollis	SP	17.1	17.1	0.5	20.7	17.0
18AA02	Hieracio-Holcetum mollis	SR	16.9	16.9	0.4	21.4	16.6
19AA01	Galio hercynici-Festucetum ovinae	SP	13.7	13.7	0.5	17.2	15.2
19AA02	Gentiano pneumonanthes-Nardetum	SP	9.6	9.4	0.3	14.9	10.9
19AA03	Botrychio-Polygaletum	SP	10.8	10.6	0.2	15.1	9.7
19AA04	Betonico-Brachypodietum	SR	12.2	12.2	0.4	18.2	15.7

syntaxon code	syntaxon	soiltype (see Table 5)	critical load in Appendix 2 (kg N $ha^{-1}.y^{-1}$)	critical load from uncertainty analysis (kg N $ha^{-1}.y^{-1}$)			
				without USV		with USV	
				mean	s.e.	mean	s.e.
20AA01	Genisto anglicae-Callunetum	SP	4.3	4.7	3.8	25.3	19.0
20AB01	Carici arenariae-Empetretum	SP	29.2	29.1	0.8	26.6	19.2
20AB02	Polypodio-Empetretum	SP	30.7	30.7	0.9	30.0	20.1
20AB03	Salici repentis-Empetretum	SP	30.2	30.2	0.9	27.7	19.3
20AB04	Pyrolo-Salicetum	SC	33.3	33.2	1.0	33.6	18.2
20AB04	Pyrolo-Salicetum	SP	31.2	31.2	1.0	31.0	20.3
22AB01	Salsolo-Cakiletum maritimae	SC	23.6	23.5	0.6	25.0	17.8
23AA01	Honckenyo-Agropyretum juncei	SC	23.6	23.7	0.6	25.1	17.8
23AB01	Elymo-Ammophiletum	SC	21.2	21.0	0.5	24.5	15.7
24AA01	Spartinetum maritimae	CC	23.2	23.3	0.6	24.9	17.8
24AA01	Spartinetum maritimae	SC	23.3	23.3	0.6	24.9	17.8
24AA02	Spartinetum townsendii	CC	23.1	23.1	0.6	24.8	17.8
24AA02	Spartinetum townsendii	SC	23.1	23.1	0.6	24.8	17.8
25AA01	Salicornietum dolichostachyae	SC	23.0	23.0	0.6	24.7	17.8
25AA02	Salicornietum brachystachyae	CC	22.8	22.9	0.6	24.6	17.7
25AA02	Salicornietum brachystachyae	CN	22.5	22.6	0.7	24.4	17.6
25AA03	Suaedetum maritimae	CC	22.9	23.0	0.6	24.6	17.7
25AA03	Suaedetum maritimae	SC	22.9	22.9	0.6	24.6	17.7
26AA01	Puccinellietum maritimae	CC	22.3	22.4	0.6	24.1	17.6
26AA01	Puccinellietum maritimae	CN	21.9	22.1	0.6	24.8	16.8
26AA01	Puccinellietum maritimae	SC	22.2	22.4	0.6	24.1	17.6
26AA02	Plantagini-Limonietum	SC	22.0	22.0	0.5	23.8	17.5
26AA03	Halimionetum portulacoides	CC	22.7	22.9	0.6	24.6	17.7
26AB01	Puccinellietum distantis	CC	22.8	22.7	0.6	24.3	17.7
26AB01	Puccinellietum distantis	CN	21.7	22.4	0.6	24.8	16.9
26AB01	Puccinellietum distantis	SC	22.5	22.7	0.5	24.3	17.7

syntaxon code	syntaxon	soiltype (see Table 5)	critical load in Appendix 2 (kg N ha^{-1}.y^{-1})	critical load from uncertainty analysis (kg N ha^{-1}.y^{-1})			
				without USV		with USV	
				mean	s.e.	mean	s.e.
26AC01	Juncetum gerardi	CC	21.0	21.0	0.4	22.9	17.3
26AC01	Juncetum gerardi	CN	20.9	20.7	0.5	23.5	16.5
26AC01	Juncetum gerardi	SC	21.0	21.0	0.4	22.9	17.3
26AC02	Armerio-Festucetum litoralis	CC	21.5	21.5	0.5	23.3	17.4
26AC02	Armerio-Festucetum litoralis	SC	21.5	21.5	0.5	23.3	17.4
26AC06	Atriplici-Elytrigietum pungentis	CC	23.0	23.1	0.6	24.6	17.7
26AC06	Atriplici-Elytrigietum pungentis	SC	23.1	23.1	0.6	24.6	17.7
26AC07	Oenantho lachenalii-Juncetum maritimi	CC	25.8	25.7	0.3	28.6	12.7
26AC07	Oenantho lachenalii-Juncetum maritimi	CN	24.6	25.3	0.4	28.0	12.9
26AC07	Oenantho lachenalii-Juncetum maritimi	SC	20.9	20.9	0.4	23.6	16.5
27AA02	Centaurio-Saginetum	SC	20.8	20.7	0.5	24.7	15.3
28AA01	Cicendietum filiformis	SP	10.9	11.3	0.3	16.7	10.8
28AA02	Isolepido-Stellarietum uliginosae	SR	15.1	15.0	0.5	12.6	11.7
29AA02	Rumicetum maritimi	CC	31.3	31.3	0.4	30.4	13.3
29AA02	Rumicetum maritimi	CN	30.6	30.5	0.5	29.5	13.7
29AA02	Rumicetum maritimi	PN	22.5	22.6	0.6	26.7	16.9
29AA02	Rumicetum maritimi	SC	23.3	23.3	0.6	26.0	16.7
29AA04	Eleocharito acicularis-Limoselletum	CC	22.1	22.2	0.5	25.2	16.5
29AA04	Eleocharito acicularis-Limoselletum	SR	21.8	21.9	0.6	23.5	17.4
30AA01	Kickxietum spuriae	CC	23.4	23.8	0.3	29.2	12.4
30AA02	Papaveri-Melandrietum noctiflori	CC	24.0	24.4	0.3	29.9	12.6
30AB01	Veronico-Lamietum hybridi	CC	24.4	24.7	0.3	30.2	12.6
30AB03	Chenopodio-Oxalidetum fontanae	CN	22.3	22.1	0.6	24.9	14.5
30AB03	Chenopodio-Oxalidetum fontanae	SR	17.5	17.5	0.7	23.2	17.4
30BA01	Scleranthο annui-Arnoseridetum	SP	19.7	19.6	0.4	20.8	16.5
30BA01	Scleranthο annui-Arnoseridetum	SR	19.8	19.6	0.5	21.6	16.4

syntaxon code	syntaxon	soiltype (see Table 5)	critical load in Appendix 2 (kg N $ha^{-1}.y^{-1}$)	critical load from uncertainty analysis (kg N $ha^{-1}.y^{-1}$)			
				without USV		with USV	
				mean	s.e.	mean	s.e.
30BA02	Papaveretum argemones	CN	21.2	21.2	0.5	22.8	13.4
30BB01	Spergulo arvensis-Chrysanthemetum	CN	21.8	21.6	0.7	23.1	13.7
30BB01	Spergulo arvensis-Chrysanthemetum	SR	17.6	18.0	0.6	22.0	17.2
31AA01	Bromo-Corispermetum	SC	22.0	21.8	0.6	24.9	15.9
31AA02	Erigeronto-Lactucetum	CC	22.9	23.3	0.3	29.6	12.8
31AA02	Erigeronto-Lactucetum	SC	22.0	22.0	0.6	25.1	16.0
31AB03	Balloto-Arctietum	CC	24.5	24.6	0.3	30.5	12.9
31AB03	Balloto-Arctietum	SC	23.3	23.0	0.7	26.0	16.0
31BA01	Echio-Verbascetum	SC	21.0	21.1	0.5	24.2	15.8
31CA02	Bromo inermis-Eryngietum campestris	CC	20.8	20.8	0.5	25.3	15.1
31CA02	Bromo inermis-Eryngietum campestris	SC	21.0	20.8	0.4	22.7	17.2
32AA01	Valeriano-Filipenduletum	CC	21.8	22.0	0.4	26.3	15.3
32AA01	Valeriano-Filipenduletum	PN	21.7	21.4	0.6	24.4	16.5
32AA01	Valeriano-Filipenduletum	SC	22.0	21.9	0.5	23.8	17.5
32BA01	Valeriano-Senecionetum fluviatilis	CC	25.9	26.1	0.3	29.2	14.0
32BA01	Valeriano-Senecionetum fluviatilis	CN	25.4	25.6	0.4	28.4	14.4
32BA02A	Soncho-Epilobietum typicum	CC	29.2	29.2	0.4	30.3	13.2
32BA02A	Soncho-Epilobietum typicum	CN	28.7	28.6	0.4	29.5	13.5
32BA02A	Soncho-Epilobietum typicum	PN	22.9	22.7	0.6	27.9	16.5
32BA03	Oenantho-Althaeetum	CC	25.6	25.9	0.3	29.6	13.2
32BA03	Oenantho-Althaeetum	CN	25.6	25.5	0.4	29.1	13.4
32BA03	Oenantho-Althaeetum	SR	21.9	22.4	0.6	24.3	17.2
35AA01	Rubetum grati	PN	33.4	33.6	0.3	38.2	11.8
35AA01	Rubetum grati	SP	29.5	27.9	7.4	29.7	15.8
35AA01	Rubetum grati	SR	29.4	29.3	0.4	32.0	13.9
35AA02	Rubetum silvatici	SP	30.2	30.4	0.4	30.3	15.9

syntaxon code	syntaxon	soiltype (see Table 5)	critical load in Appendix 2 (kg N ha^{-1}.y^{-1})	critical load from uncertainty analysis (kg N ha^{-1}.y^{-1})			
				without USV		with USV	
				mean	s.e.	mean	s.e.
35AA02	Rubetum silvatici	SR	29.1	29.3	0.4	32.1	13.7
36AA01	Salicetum auritae	PN	36.7	36.6	0.6	38.0	12.7
36AA01	Salicetum auritae	SP	28.7	27.4	5.8	24.6	14.7
36AA02	Salicetum cinereae	CC	38.8	38.7	0.6	36.7	11.4
36AA02	Salicetum cinereae	PN	22.4	22.5	0.5	27.0	14.0
37AB01	Pruno-Crataegetum	CC	32.1	32.4	0.4	36.1	11.0
37AB01	Pruno-Crataegetum	CN	23.7	23.8	1.8	27.6	12.1
37AB02	Roso-Juniperetum	SP	28.5	28.6	0.4	28.2	15.6
37AB02	Roso-Juniperetum	SR	27.4	27.5	0.4	30.3	13.4
37AC01	Hippophao-Sambucetum	SC	29.0	28.9	0.4	31.7	11.9
37AC02	Hippophao-Ligustretum	SC	28.0	27.9	0.4	30.7	11.9
37AC03	Rhamno-Crataegetum	SC	27.9	27.9	0.4	30.8	11.7
37AC04	Pruno spinosae-Ligustretum	CC	36.5	36.8	0.3	38.7	9.0
37AC05	Orchio-Cornetum	CC	37.1	37.2	0.3	38.9	9.0
38AA01	Artemisio-Salicetum albae	CC	35.1	35.4	0.4	37.6	10.8
38AA01	Artemisio-Salicetum albae	SC	28.9	29.0	0.4	31.0	14.5
38AA02	Irido-Salicetum albae	CC	40.6	40.4	0.5	39.2	10.6
38AA02	Irido-Salicetum albae	CN	30.0	30.1	0.4	30.4	11.8
38AA03	Cardamino amarae-Salicetum albae	CC	39.1	39.1	0.4	39.1	10.8
38AA03	Cardamino amarae-Salicetum albae	CN	29.0	28.9	0.4	30.4	11.9
39AA01	Thelypterido-Alnetum	CN	28.5	28.4	0.5	29.8	10.8
39AA01	Thelypterido-Alnetum	PN	36.5	36.8	0.5	39.1	13.2
39AA02	Carici elongatae-Alnetum	PN	36.4	36.4	0.5	38.9	13.3
39AA02	Carici elongatae-Alnetum	SR	30.7	30.8	0.4	34.5	14.2
40AA01	Erico-Betuletum pubescentis	PN	32.4	33.2	0.3	37.3	11.7
40AA01	Erico-Betuletum pubescentis	SP	15.8	15.7	1.4	28.1	14.7

syntaxon code	syntaxon	soiltype (see Table 5)	critical load in Appendix 2 (kg N $ha^{-1}.y^{-1}$)	critical load from uncertainty analysis (kg N $ha^{-1}.y^{-1}$)			
				without USV		with USV	
				mean	s.e.	mean	s.e.
40AA02	Carici curtae-Betuletum pubescentis	CN	26.9	26.9	0.5	28.9	10.6
40AA02	Carici curtae-Betuletum pubescentis	PN	34.8	34.8	0.5	37.2	13.0
41AA01	Dicrano-Juniperetum	SP	33.0	33.1	1.0	30.3	14.5
41AA02	Cladonio-Pinetum sylvestris	SP	8.5	9.6	4.9	29.0	14.0
41AA03	Leucobryo-Pinetum	SP	33.8	30.4	8.9	31.1	14.8
42AA01	Betulo-Quercetum roboris	SP	10.5	13.6	8.3	26.0	14.7
42AA02	Fago-Quercetum	SP	29.1	29.1	0.4	29.5	15.3
42AA02	Fago-Quercetum	SR	28.1	28.1	0.4	31.3	13.4
42AA03	Deschampsio-Fagetum	SP	29.4	29.2	2.6	28.5	15.8
42AA03	Deschampsio-Fagetum	SR	28.2	28.5	0.4	30.7	13.9
42AB01	Luzulo luzuloidis-Fagetum	SP	28.0	28.2	0.4	29.5	15.8
43AA01	Violo odoratae-Ulmetum	SC	29.1	29.2	0.4	30.2	14.7
43AA02	Fraxino-Ulmetum	CC	32.3	32.7	0.3	36.2	11.0
43AA02	Fraxino-Ulmetum	CN	23.6	23.8	0.4	27.6	12.0
43AA03	Crataego-Betuletum pubescentis	SC	27.9	27.6	0.4	31.1	11.2
43AA05	Pruno-Fraxinetum	CN	24.5	24.5	0.4	27.9	11.9
43AA05	Pruno-Fraxinetum	SR	12.9	12.9	0.5	17.9	13.6
43AB01	Stellario-Carpinetum	CC	37.8	38.0	0.3	39.4	9.1
43AB01	Stellario-Carpinetum	CN	22.7	22.4	0.4	27.6	11.2
43RG03	RG Urtica dioica [Circaeo-Alnenion]	CC	35.7	35.8	0.4	37.5	10.7
43RG03	RG Urtica dioica [Circaeo-Alnenion]	CN	26.1	26.0	0.4	28.7	12.1
43RG03	RG Urtica dioica [Circaeo-Alnenion]	PN	30.5	30.4	0.4	27.1	11.9

Appendix 4 critical loads per Nature Target Type (NTT).

Values are the minimum and maximum, respectively, over the association - soil combinations belonging to each NTT (on the basis of data in Bal et al. 2001). Numbers of 'determinative' associations are directly taken from Bal et al.; the number of these associations for which critical loads were determined are also given. Note that the actual critical loads per association can be based on more than one soil type, so that even in cases where there is only one association per NTT the minimum and maximum values can be different. Critical load values are not determined for NTT's where (a) its constituent associations are not in the present analysis, or (b) Bal at al. give a specific soil type for that NTT, but no critical load was determined for its constituent associations on that soil type.

NTT code	Dutch name	number of 'determi-native' associations	number of associations used to determine critical load	critical load range (kg N $ha^{-1}.y^{-1}$)	
				MIN	MAX
3.1	Droogvallende bron en beek	4	1	19.2	19.2
3.2	Permanente bron	3	1	19.2	19.2
3.3	Snelstromende bovenloop	6	1	19.2	19.2
3.4	Snelstromende midden- en benedenloop	2	0	-	-
3.5	Snelstromend riviertje	1	0	-	-
3.6	Langzaam stromende bovenloop	5	1	19.2	19.2
3.7	Langzaam stromende midden- en benedenloop	1	0	-	-
3.8	Langzaam stromend riviertje	2	0	-	-
3.9	Snelstromende rivier en nevengeul	1	0	-	-
3.10	Langzaam stromende rivier en nevengeul	1	0	-	-
3.11	Zoet getijdenwater	4	1	22.2	23.2
3.12	Brak getijdenwater	2	0	-	-
3.13	Brak stilstaand water	7	0	-	-
3.14	Gebufferde poel en wiel	7	0	-	-
3.15	Gebufferde sloot	8	0	-	-
3.16	Dynamisch rivierbegeleidend water	2	1	23.5	23.5

NTT code	Dutch name	number of 'determi-native' associations	number of associations used to determine critical load	critical load range (kg N $ha^{-1}.y^{-1}$)	
				MIN	MAX
3.17	Geïsoleerde meander en petgat	5	1	29.7	29.7
3.18	Gebufferd meer	5	0	-	-
3.19	Kanaal en vaart	5	0	-	-
3.20	Duinplas	4	1	12.2	12.2
3.21	Zwakgebufferde sloot	3	0	-	-
3.22	Zwakgebufferd ven	4	1	21.1	22.0
3.23	Zuur ven	2	1	31.1	33.1
3.24	Moeras	8	4	20.5	31.3
3.25	Natte strooiselruigte	6	2	21.7	29.2
3.26	Natte duinvallei	4	4	17.7	22.0
3.27	Trilveen	1	1	15.8	15.8
3.28	Veenmosrietland	1	1	7.2	7.2
3.29	Nat schraalgrasland	2	2	1.8	18.1
3.30	Dotterbloemgrasland van beekdalen	3	2	11.4	19.9
3.31	Dotterbloemgrasland van veen en klei	2	2	17.6	23.7
3.32	Nat, matig voedselrijk grasland	3	2	21.4	22.4
3.33	Droog schraalgrasland van de hogere gronden	3	3	13.7	14.7
3.34	Droog kalkarm duingrasland	2	2	11.2	14.1
3.35	Droog kalkrijk duingrasland	5	5	16.2	21.0
3.36	Kalkgrasland	2	2	12.2	20.6
3.37	Bloemrijk grasland van het heuvelland	4	3	15.0	23.7
3.38	Bloemrijk grasland van het zand- en veengebied	2	2	15.0	18.0
3.39	Bloemrijk grasland van het rivieren- en zeekleigebied	5	4	15.0	23.7
3.40	Kwelder, slufter en groen strand	12	11	17.7	23.1
3.41	Binnendijks zilt grasland	5	5	21.4	23.1

NTT code	Dutch name	number of 'determi-native' associations	number of associations used to determine critical load	critical load range (kg N $ha^{-1}.y^{-1}$)	
				MIN	MAX
3.42	Natte heide	3	3	8.7	32.9
3.43	Natte duinheide	1	1	30.6	30.6
3.44	Levend hoogveen	8	4	26.4	33.1
3.45	Droge heide	2	1	4.3	4.3
3.46	Droge duinheide	3	3	29.2	30.7
3.47	Zandverstuiving	1	1	10.4	10.4
3.48	Strand en stuivend duin	5	3	21.2	23.6
3.49	Rivierduin en -strand	5	5	15.5	22.9
3.50	Akker van basenrijke gronden	6	6	17.5	24.4
3.51	Akker van basenarme gronden	3	1	21.2	21.2
3.52	Zoom, mantel en droog struweel van de hogere gronden	9	8	16.9	33.0
3.53	Zoom, mantel en droog struweel van het rivieren- en zeekleigebied	3	2	22.8	32.1
3.54	Zoom, mantel en droog struweel van de duinen	9	6	19.7	29.0
3.55	Wilgenstruweel	2	2	22.4	38.8
3.56	Eikenhakhout en -middenbos	2	2	10.5	29.1
3.57	Elzen-essenhakhout en -middenbos	2	2	23.6	36.4
3.58	Eiken-haagbeukenhakhout en -middenbos van het heuvelland	1	1	22.7	37.8
3.59	Eiken-haagbeukenhakhout en -middenbos van zandgronden	1	0	-	-
3.60	Park-stinzenbos	2	2	23.6	32.3
3.61	Ooibos	2	2	29.0	40.6
3.62	Laagveenbos	3	3	30.5	36.5
3.63	Hoogveenbos	3	2	32.4	34.8
3.64	Bos van arme zandgronden	3	3	8.5	33.8
3.65	Eiken- en beukenbos van lemige zandgronden	2	2	28.1	28.2
3.66	Bos van voedselrijke, vochtige gronden	2	2	23.6	32.3

NTT code	Dutch name	number of 'determi-native' associations	number of associations used to determine critical load	critical load range (kg N $ha^{-1}.y^{-1}$)	
				MIN	MAX
3.67	Bos van bron en beek	2	2	12.9	36.4
3.68	Eiken-haagbeukenbos van het heuvelland	1	1	22.7	37.8
3.69	Eiken-haagbeukenbos van zandgronden	1	0	-	-