Demonstration Project for the Development of Integrated Management Plans for Catchment Areas of Small Trans-Border Lowland Rivers: the River Dommel

Universiteit Utrecht

4. Habitat and Vegetation Response Prediction for Meadows and Fens

Application of SMART-MOVE on a Regional Scale

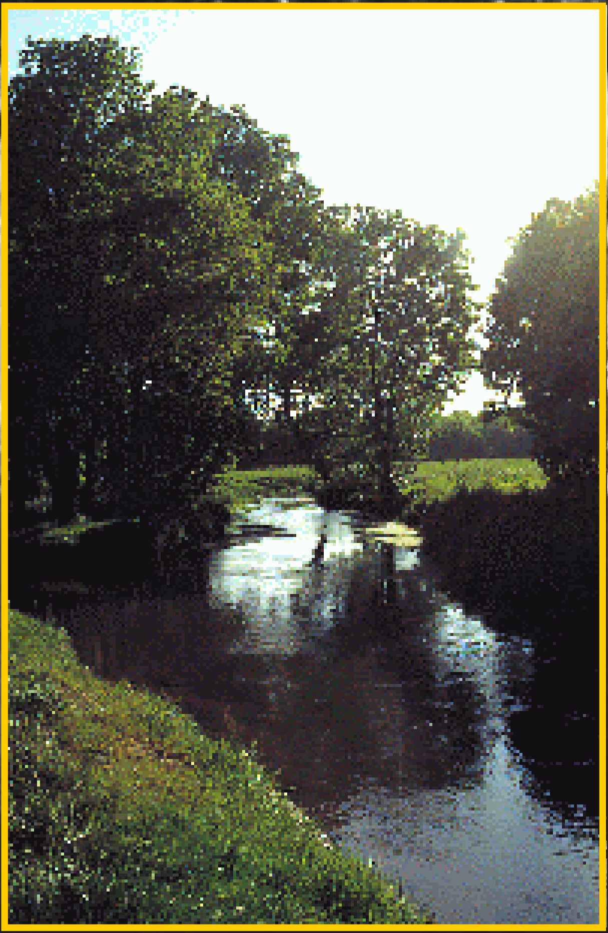
N. M. Pieterse
H. Olde Venterink
P.P. Schot
M.J. Wassen
A.W.M. Verkroost

Provincie
Noord Brabant

Waterschap
de Dommel

Vlaamse Milieu
Maatschappij

Life



DEMONSTRATION PROJECT FOR THE DEVELOPMENT OF INTEGRATED MANAGEMENT PLANS FOR CATCHMENT AREAS OF SMALL TRANS-BORDER LOWLAND RIVERS: THE RIVER DOMMEL

4. Habitat and Vegetation Response Prediction for Meadows and Fens

Application of SMART-MOVE on a Regional Scale

N. M. Pieterse
H. Olde Venterink
P.P. Schot
M. J. Wassen
A.W.M. Verkroost

The Netherlands Centre for Geo-ecological Research (ICG)
Functioning of Landscape Ecosystems Research Group.
Department of Environmental Science, Utrecht University

Utrecht, 1998

Demonstration project for the Development of Integrated Management Plans for Catchment Areas of Small Trans-Border Lowland Rivers: the River Dommel

Administrative project leader: Ir. A. Span (Province of North Brabant, NL)
Scientific project leader: Dr. A.W.M. Verkroost (Utrecht University, NL)

PO Box 80115
3508 TC Utrecht,
The Netherlands

ISBN 90-73083-22-2

CONTENTS

Figures

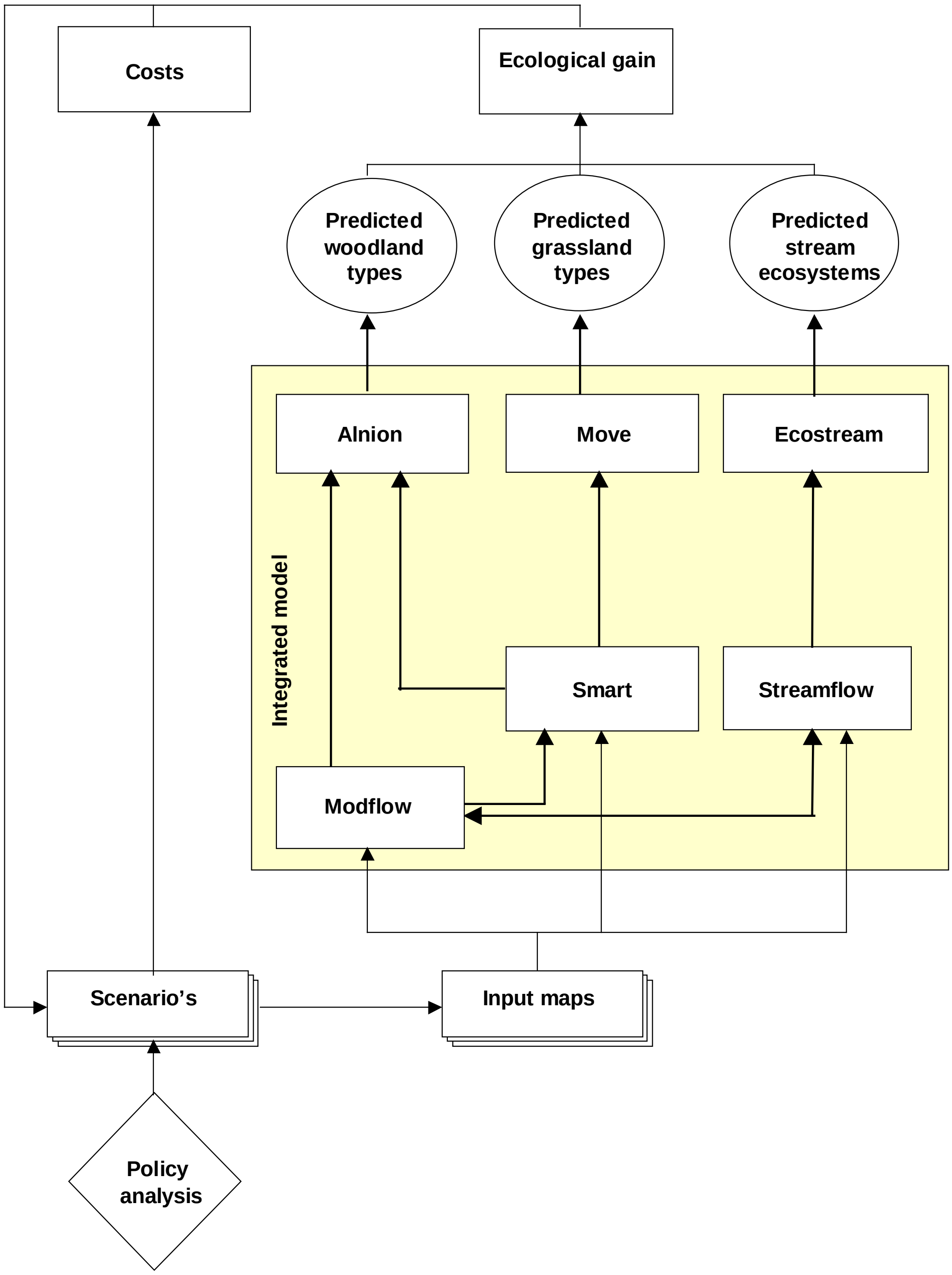
Tables

APPENDICES

Preface

This publication is part of a series of technical reports concerning the EU-LIFE demonstration project for the development of integrated management plans for trans-border lowland river catchments. For this project the Dutch-Belgian catchment area of the river Dommel served as a case area.

The project aimed at the development of scientifically sound environmental impact-assessment tools on the one hand, and the construction of viable plans on the other. Administrative project coordination was carried out by the Province of North Brabant, scientific project coordination by Utrecht University. The methodological structure of the project is shown in the next figure.



Construction of the groundwater model (based on MODFLOW), the development of the models STREAMFLOW, ALNION, and ECOSTREAM, and integration of all models in a Geographical Information System were carried out by Utrecht University. MOVE originates from the National Institute of Public Health and Environment (RIVM), and SMART from the Winand Staring Center for Integrated Land, Soil and Water Research (SC-DLO). MOVE and SMART were adjusted to a regional scale, rewritten in ARC-INFO, and calibrated for this project by Utrecht University. The model ECOSTREAM is primarily based on the Aquatic Ecotope System as developed by the Institute for Forestry and Nature Research (IBN-DLO) and the University of Leiden. Policy scenarios were developed by SC- DLO and the University of Nijmegen, in cooperation with Dutch and Belgian policy actors of the Dommel catchment. Evaluation of the costs and ecological gains of the scenarios was carried out by SC-DLO. For further information about the project one is referred to the first report in this series: Ecohydrological Modeling and Integrated Management Planning in the Catchment Area of the River Dommel. A list of all reports in this series is shown at the last page of this report.

To reach the project objectives, a good cooperation between policy makers from both sides of the Dutch-Belgian border, and scientists was very important. Due to the enthusiastic contribution of all participants to this large and complicated project, it was completed successfully. The following persons participated in the supervising committee of this project:

A.S.W. Span	(chairwoman)	Province of North Brabant,The Netherlands
J.S. ten Veldhuis	(Secretary)	Province of North Brabant, The Netherlands
A.W.M. Mol		Province of North Brabant, The Netherlands
J. Hemelraad		Water board the Dommel,The Netherlands
Y. Ronse		Flemish Environmental Company (VMM), Belgium
M. Lambrichts		Administration for Environment, Nature and Land use (AMINAL), Belgium.
G. Lambrechts		Administration for Environment, Nature and Land use (AMINAL), Belgium.
G. Vanderwaeren		Administration for Environment, Nature and Land use (AMINAL), Belgium.
H. Awouters		Province of Limburg, Belgium
J. van Rijen		Ministry of Agriculture, Nature conservation and Fisheries (LNV), The Netherlands

Summary

To assess the impact of integrated management plans on brook valley ecosystems in the catchment area of the river Dommel, an integrated landscape ecological model is developed. Within this integrated model the Nature Planner (developed at the national institute of the public health and the environment (RIVM)) is used to predict effects for meadow and fen vegetation. Because the Nature Planner was developed for use at the National scale, it could not directly be applied for the regional scale of the Dommel catchment. Therefore the fundament of the nature planner, the models SMART2 developed at the DLO-Staring Centre) and MOVE (developed at the RIVM), were rewritten for application within the GIS ArcInfo to implement the flexibility of a GIS.

Vegetation response prediction is carried out with the model MOVE, using three environmental variables: acidity, nutrient availability and wetness of a site. All three variables are based upon Ellenberg indication values, which have to be calibrated to measurable environmental habitat conditions. Calibration of Ellenberg indication values for acidity and wetness was already carried out. Calibration of Ellenberg-N indication values to measured nutrient availability of the soil was still necessary. Therefore a comprehensive field experiment in the catchment areas of the Dommel and the Zwarte Beek (B) was carried out. This experiment resulted in a significant relationship between Ellenberg-N indication values and net annual N-mineralization.

The variables N-mineralization and acidity are simulated with the model SMART2. The variable wetness is implemented as the mean spring groundwater level, simulated with a hydrological model of the catchment area by Pieterse *et al* (1998a, 1998b).

SMART2 simulations are compared with measurements in the Dommel catchment. Simulations of acidity are comparable with measured acidity. N-mineralization simulations do not match with field observations. Moreover, these simulations do not differentiate between various sites, although these sites have different soil properties and different hydrological regimes. The MOVE variable Ellenberg-N is therefore excluded from the MOVE equations. Because the multiple regression equations of MOVE cannot be altered, the optimum N for each plant species is used instead.

MOVE simulations were carried out for the catchment area of the river Dommel. Simulations are in agreement with expectations of potentials for nature development, based upon fieldwork. The simulations show that in the larger part of the catchment, the probability of occurrence of species-rich grasslands and fens is very low for the current hydrological situation. At some locations however, a relative high probability of occurrence for *Calthion palustris* and *Junco-Molinion* is simulated. Because habitat conditions in the Dommel catchment are more likely to be eutrophic than oligothropic, the probability of occurrence of oligothrophic and mesothrophic vegetation types (*Junco-Molinion, Caricion nigrae and Calthion palustris*) is overestimated. From inventories of the occurrence of grasslands and fens in this catchment, it is concluded that hardly any of these vegetation types, and especially the species-rich types, are left. Therefore a validation of model simulations is not carried out.

Samenvatting

Voor het stroomgebied van de Dommel is een geintegreerd landschaps-ecologisch model ontwikkeld om de effecten van geintegreerde beheersplannen in te kunnen schatten. Binnen dit geintegreerde model wordt de Natuurplanner (ontwikkeld bij het RIVM) gebruikt om voorspellingen uit te voeren voor extensieve grasland-vegetaties. Omdat de Natuurplanner is ontwikkeld voor het gebruik op nationale schaal, kon het niet direct worden toegepast op het regionale schaalniveau van het stroomgebied van de Dommel. Daarom zijn de bouwstenen van de Natuurplanner, de modellen SMART2 (ontwikkeld bij het DLO-Staring Centrum) en MOVE (ontwikkeld bij het RIVM) geimplementeerd binnen het GIS programma ArcInfo.

Voorspellingen van de vegetatie responsie wordt uitgevoerd met het model MOVE waarbij er gebruik wordt gemaakt van drie standplaatsfactoren: zuurgraad, nutrienten-beschikbaarheid en vocht. Deze drie variabelen zijn gebaseerd op Ellenberg indicatie getallen. Het is noodzakelijk deze variabelen te calibreren met meetbare omgevingsvariabelen. Voor de variabelen zuurgraad en vocht is dit reeds uitgevoerd. Voor nutrienten-beschikbaarheid was calibratie nog steeds nodig. Daarom is een intensief veldexperiment uitgevoerd in de stroomgebieden van de Dommel en de Zwarte Beek (B). Dit experiment leverde een significante relatie op tussen Ellenberg-N en netto N-mineralisatie.

De meetbare variabelen N-mineralisatie en zuurgraad worden berekend door het model SMART2. De variabele vocht, geimplementeerd als gemiddelde voorjaars grondwaterstand, wordt berekend door een hydrologisch model van het stroomgebied van de Dommel (Pieterse *et al*, 1998a, 1998b).

SMART2 berekeningen zijn vergeleken met metingen uitgevoerd in het stroomgebied van de Dommel. Zuurgraad berekeningen blijken goed aan te sluiten bij metingen. Echter, berekeningen van N-mineralisatie zijn niet vergelijkbaar met veldwaarnemingen. Tevens blijken deze simulaties niet diffentierend te zijn voor de verschillende locaties alhoewel deze locaties een verschillende bodem, en verschillende hydrologische omstandigheden hebben. Als gevolg hiervan is de MOVE variabele Ellenberg-N niet opgenomen in de responsie vergelijkingen. Omdat deze vergelijkingen niet kunnen worden aangepast is ervoor gekozen om voor elke te voorspellen plantesoort de optimale Ellenberg-N waarde in te vullen.

SMART-MOVE is toegepast op het stroomgebied van de Dommel. De simulaties zijn in overeenstemming met verwachte potenties voor natuurontwikkeling in het stroomgebied, waargenomen via veldwerk. De simulaties laten zien dat in het grootste deel van het stroomgebied de kans op voorkomen van soortenrijke graslandvegetaties voor de huidige hydrologische situatie erg laag is. Op sommige lokaties echter blijkt er een relatief hoge kans op het voorkomen van dotterbloem-hooilanden (*Calthion palustris*) en blauwgraslanden (*Junco-Molinion*) te zijn. Omdat de standplaatscondities in het stroomgebied van de Dommel eerder eutroof dan oligotroof zijn is het waarschijnlijk dat de kans op voorkomen van oligotrofe en mesotrofe vegetatietypen (*Junco-Molinion, Caricion nigrae* en *Calthion palustris*) kleiner is dan word gesimuleerd. Uit inventarisaties van in het veld waargenomen extensieve graslanden werd geconcludeerd dat er bijna geen extensieve graslanden, en vooral bijna geen soortenrijke grasland-vegetaties, meer over zijn in dit stroomgebied. Daarom is een validatie van MOVE simulaties voor grasland-vegetaties niet uitgevoerd.

1. Introduction

Up to the 1960's brook valleys in the catchment area of the river Dommel contained large areas with species-rich fens, meadows and alder woods (van Leeuwen, 1966; Pedroli, 1989). Most of these wet terrestrial ecosystems have deteriorated during the last decades and the remaining part is threatened by further socio-economic developments (Pedroli, 1989; Olde Venterink et al, 1998). Major environmental problems in the brook valleys are eutrophication, acidification, and lowering of the groundwater level (Pedroli & Borger, 1990).

In the catchment area of the river Dommel brook valleys form a major part of the ecological zone. The still existing species-rich meadows, fens and alder woods function as a source of plant species for wetland regeneration. It is obvious that for the sake of regeneration of wetlands and for a successful (re)construction of the ecological zone in the Dommel catchment, deterioration of these species rich wetlands should be stopped. Therefore it is important to enable regional policy makers to assess the impact of interventions in the landscape on these brook valleys.

During the last decades, a number of models have been constructed in the Netherlands to predict vegetation response on (hydrological) habitat change (see for overviews, (Wassen & Schot, 1992; Olff, 1992; Olde Venterink & Wassen, 1997). These ecohydrological models appeared to be a powerful tool for environmental impact assessment, and subsequently policy making.

Recently at the national institute of the public health and the environment (RIVM) the Nature Planner was developed. The Nature Planner is a decision-support model for policy decisions in the field of nature and environment. The most important function of the Nature Planner is the evaluation of the consequences of economic scenarios through hydrological changes and the emission and deposition of substances on ecosystem quality in The Netherlands (Latour *et al*., 1997). The fundament of this Nature Planner is formed by the models SMART-2 (developed at the DLO-Staring Centre) and MOVE (developed at the RIVM).

For the catchment area of the river Dommel an integrated landscape ecological model is developed. To assess the impact of integrated management plans—developed in co-operation between regional authorities at both sides of the Belgian-Dutch border—on brook valley ecosystems. Within this integrated model the Nature Planner is used to predict effects for meadow and fen vegetation. Because the Nature Planner was developed for the use at national scale level, it could not directly be applied for the regional scale of the Dommel catchment. Therefore the models SMART-2 and MOVE were rewritten for application within the GIS ArcInfo. This report describes how the models SMART-2 and MOVE are used in the integrated model. In addition, simulations of SMART-MOVE are compared with the observed occurrence of meadows and fens in the catchment area of the river Dommel.

1.1 The SMART-MOVE concept

SMART-MOVE is a joint project of the national institute of public health and the environment (RIVM) and the SC-DLO (e.g: Latour & Reiling, 1993; Wiertz, van Dijk & Latour, 1992; Latour, Reiling & Wiertz, 1993; Kros *et al*., 1995; Kros, in prep). The combination of MOVE and SMART-2 is also the fundament of the Nature Planner, which was developed recently at the RIVM (Latour *et al*., 1997).

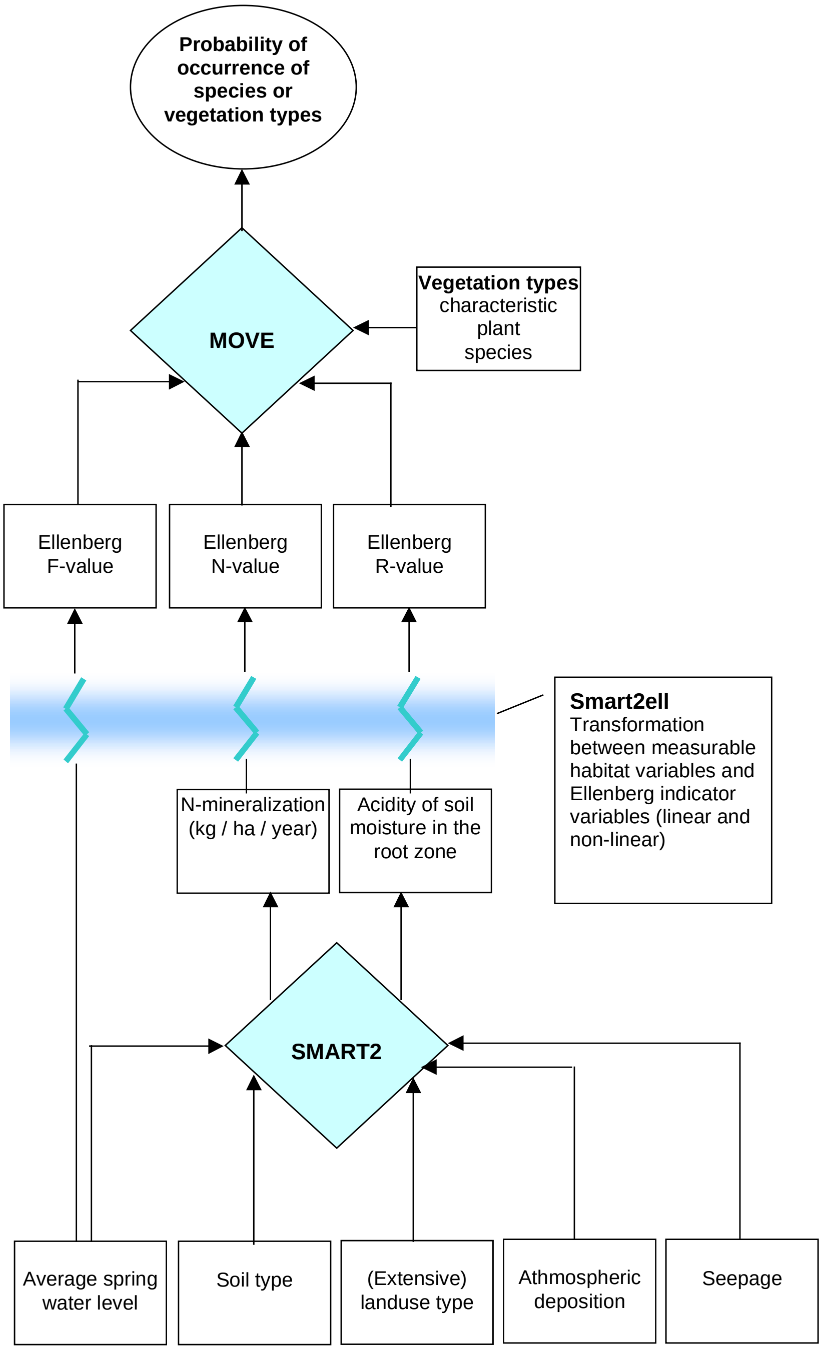


Figure 1: Flow diagram of the Smart/Move model.

Figure 1 is a flowchart of the model integration of SMART-2, MOVE and the required data, as applied in the Dommel catchment. First, the model SMART2 calculates the available amount of nitrogen and acidity of soil moisture in the root zone. The input data for SMART2 are GIS maps of seepage, atmospheric deposition, average spring water groundwater levels, soil type and vegetation type (extensive grassland, forest, heather). Next, the two variables calculated by SMART2 —acidity and nutrient availability— and the available amount of moisture are the core variables of the vegetation prediction model MOVE. Because MOVE does not use the measurable variables but relative variables on an ordinal scale (Ellenberg values), translation between the output of SMART2 and MOVE is necessary. Finally, the Ellenberg values are used to predict the probability of occurrence of single plant species. Prediction of vegetation types is applied with a set of species that is characteristic for the desired vegetation type. The regression equations for prediction of plant species and most decision rules are equal to those in the Nature Planner.

1.2 Application on a regional scale

In the nature planner, calculations for environmental evaluations and RIVM scenario's are performed with grid cells of 250 x 250 meters wide (Kros, in prep). scaled up to 5km x 5km cells. For small river catchments, higher detail is preferable because river valleys can be as small as 100 meters. Because the input routine of SMART2 is rewritten for application within the GIS ArcInfo and MOVE is completely rewritten in the ArcInfo environment, calculations can be performed on every level of detail. The combination SMART2 and MOVE is applied for the Dommel valleys with a resolution of simulation of 100x100 m. The results are aggregated to 500x500 meter cells.

With the GIS ArcInfo, a selection is made of a unique combination of vegetation, soil, seepage quantity, seepage type and mean spring groundwater level (with the combine function). SMART-MOVE is applied on each unique combination. SMART-MOVE is rewritten into 3 basic modules: SMART2, SMART2MOVE and MOVE (see Figure 1). The first module is the original SMART2 module, with a newly developed ArcInfo interface. The module SMART2MOVE performs the conversion of measurable values (pH, N-mineralization, mean spring groundwater level) to Ellenberg indication values (respectively R, N and F). Finally, the module MOVE calculates probability of occurrence for plant species or groups of species (vegetation types).

2. MOVE

2.1 The Model Concept

The model MOVE predicts the probability of the occurrence of plant species. The probability of occurrence is a function of the habitat conditions soil acidity, trophic level, and soil moisture using response curves (e.g. Figure 2). In contrast to empirical statistical models, like ICHORS, ITORS and HYVEG where measured environmental conditions are used to fit response curves (Olde Venterink & Wassen, 1997), MOVE uses Ellenberg indication values (Ellenberg *et al*., 1991). To describe a response curve, an optimum and tolerance is needed. The Ellenberg indication values can be considered as optima without tolerances. To enable the Ellenberg indication values for vegetation prediction the tolerances had to be estimated. This is done by averaging the Ellenberg indication values of all present species in a vegetation releveé of a location. This analysis is performed for many locations. The tolerance of the Ellenberg indication value for each species can now be calculated using all average Ellenberg values for all locations where the species occurs (e.g. ter Braak & Gremmen, 1987).

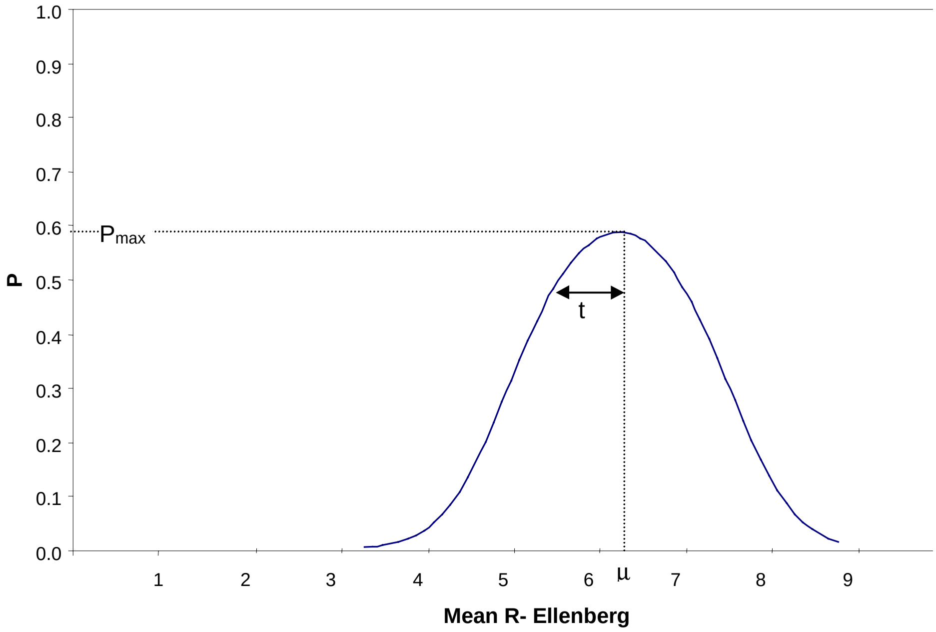


Figure 2: Gaussian response curve of a species fitted on acidity (R-Ellenberg). μ *= optimum; t = tolerance;* P_{max} *= maximum probability of occurrence.*

The advantage of using Ellenberg indication values in stead of measured environmental conditions is the very large amount of relevées that can be obtained to determine response curves. For MOVE regression analysis was based on 30.000 vegetation relevées (Latour *et al*., 1997). Until now the occurrence frequency is described with Gaussian logistic regression models (Figure 2) (e.g. Ter Braak and Looman; ter Braak & Looman, 1986; Jongman, ter Braak & van Tongeren, 1995). The use of other response models is currently under study (Bio, Alkemade & Barendregt, 1998).

For about 900 plant species multiple response curves, that is: response curves based upon more than one variable, are implemented in MOVE. The probability of plant species occurrence can be calculated by means of the equations defined by Latour *et al*., (1997).

The probability of occurrence of a plant species (*P*):

$$P = \frac{e^{f(x)}}{1 + e^{f(x)}}$$

Where *f(x)* is calculated with:

$$f(x) = y + b1 * F + b2 * F^2 + b3 * R + b4 * R^2 + b5 * N + b6 * N^2 + b7 * F * R + b8 * F * N + b9 * R * N$$

P = *Probability of plant species occurrence* *(-)*
f (x) = *Linear predictor* *(-)*
y, b1 - b9 = *Intercept and regression parameters; unique for every species* *(-)*
F, R, N = *Ellenberg indication values for moisture, acidity and nutrient availability* *(-)*

MOVE predicts the probability of occurrence of individual plant species in relation to Ellenberg indication values for moisture, acidity and nutrient availability. Therefore an essential step for application on a real site is translation of measurable (abiotic) site variables to Ellenberg indication values. This step is described in paragraph 2.2.

Besides response prediction for individual plant species, predictions can also be made for combinations of plant species. In the Nature Planner predictions are made for plant communities (Loopstra & Maarel), 'natuurdoeltypen' (Bal *et al.*, 1995), and ecotope types (Runhaar et al, 1987). For application of MOVE in the Dommel catchment we made groups of plant species according to the vegetation composition distinguished by Schaminée *et al.* (1995; 1996).

The probability of occurrence of vegetation types can be assessed using the individual response curves of the characteristic plant species. In the nature planner, the completeness of a vegetation type is assessed by estimating the ‘actual’ occurrence of individual species. A plant species occurs if the simulated probability of occurence exceeds a certain treshold value. The amount of plant species within a vegetation type exceeding this treshold value gives an indication of the completeness of that type. The disadvantage of this method however is that the simulated vegetation types are difficult to compare with each other. To avoid this problem, the average probability of occurrence of a vegetation type is calculated instead. This is done by averaging the probability of occurrence of all characteristic species within a vegetation type (see box below).

The probability of occurence of a vegetation type (P_{type}):

$$P_{type} = \frac{\underset{i=1,n_{spec}}{P_i}}{n_{spec}}$$

P_{type} = *Probability of occurrence of a vegetation type*
n_{spec} = *Number of species that represent a vegetation type*
P_i = *Actual probability of occurrence of plant species i.*

2.2 Calibration of Ellenberg values with measured habitat conditions

For MOVE an essential model step is the transformation of environmental variables to Ellenberg indication values. For this purpose, Ellenberg indication values have to be calibrated with (measurable) environmental variables. Calibration of Ellenberg indication values is carried out using data sets with vegetation relevées and measured environmental conditions at the site of the vegetation relevée. For every site the average Ellenberg values for moisture, acidity and nutrient availability are calculated by averaging the Ellenberg indication values of all occurring plant species. By means of regression the relationships were determined between these average Ellenberg indication values and the measured environmental variables of the sites. The environmental variables that correlate best with the average Ellenberg indication values are implemented in the SMART-MOVE model. The regression equations for application of SMART-MOVE in the Dommel catchment are implemented in the module SMART2ELL.

For moisture and acidity successful calibrations were carried by (Alkemade, Wiertz & Latour, 1996) and Ertsen *et al.* (1998). The Ellenberg indication values for nutrient availability could only be correlated successful with above ground biomass (Alkemade *et al*., 1996). To find an environmental variable that correlates with the Ellenberg indication values for nutrient availability, a comprehensive field experiment in the catchment areas of the Dommel and the Zwarte Beek was carried out for this study.

2.2.1 moisture

The Ellenberg indication values for moisture (F) were successfully calibrated with mean spring groundwater levels ((Alkemade *et al*., 1996); (Ertsen, Alkemade & Wassen, 1998)). In the Nature Planner one regression equation was obtained for this calibration. However both (Alkemade *et al*., 1996) and Ertsen *et al*, (1998) found that the regression equations for the Ellenberg F values with the mean spring groundwater levels were different for the soil types sand, peat and clay. These three different regression equations are used for application of SMART-MOVE in the Dommel catchment. The regression equations of (Alkemade *et al*., 1996) were preferred to those of Ertsen *et al.* (1998) because the calibrations of Alkemade were mainly carried out with data from sites in pleistocene parts of The Netherlands (data from (Runhaar, 1989)). This data set is more comparable to the Dommel catchment then the sites of Ertsen *et al* (1998) which are mainly located in North-Holland. The relationships between Ellenberg F-indication values and mean spring groundwater levels for sand, peat, and clay, according to Alkemade et al (1996) are shown in Figure 3.

For very dry areas (average Ellenberg F indication value < 3.9; mean spring groundwater level < 150 cm below surface level) no mean spring water levels were collected. In the Nature Planner the assumption is made that the theoretically lowest Ellenberg F value (1) should match with the lowest spring groundwater level measured in The Netherlands. To comply with this assumption, a different theoretical regression equation is obtained for the Ellenberg traject between 1 and 3.9 (Latour et al, 1997). For the sake of completeness this regression equation is adopted for application of SMART-MOVE in the Dommel catchment.

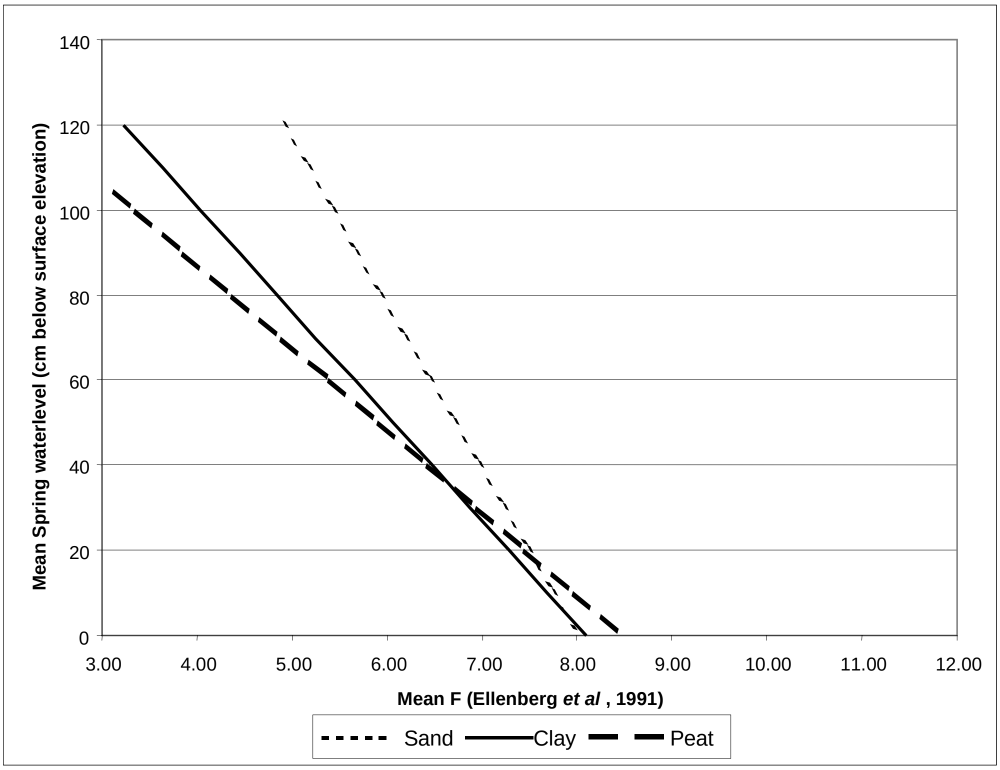


Figure 3: Relationships between Ellenberg F-indication values and mean spring groundwater levels for sand, peat, and clay areas determined by Alkemade et al (1996) based on data of Runhaar (1989).

2.2.2 acidity

The Ellenberg R values for acidity were successfully calibrated with pH-H_2O of the soil (Alkemade et al, 1996; Ertsen *et al* (1998). In both studies similar non-linear relationships were found between average Ellenberg R values and pH-H_2O of the soil. The regression equation determined by Alkemade et al (1997) as used in the Nature Planner is also used in the application of SMART-MOVE in the Dommel catchment.

The pH predicted by SMART-2 is representative for acidity of the soil moisture in the root zone (chapter 4). To match SMART-2 with MOVE, an additional regression found by Kros (in prep) between pH-H_20 and pH-soil moisture is implemented in the nature planner. He found different relationships between the two acidity variables for sand and peat soils. These soil dependent regression equations for translation of pH-soil moisture to pH-H_20 are applied for the Dommel catchment.

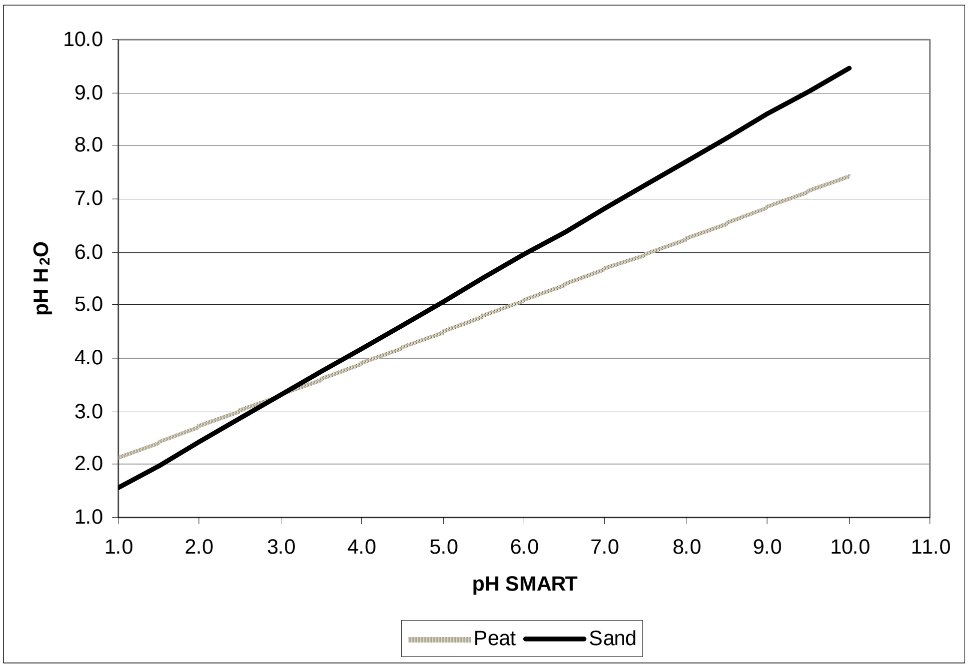


Figure 4: Relationships between pH SMART (representing the pH of soil moisture in the root zone) and pH-H_2O for two soil types (Kros, in prep.).

2.2.3 nutrient availability

In previous studies, the Ellenberg indication values for nutrient availability could only be correlated with above ground biomass, not with environmental variables (Alkemade et al; 1996; Ertsen *et al*., 1998). To match Ellenberg indication values for nutrient availability with measurable variables, a comprehensive field experiment in the catchment areas of the Dommel and the Zwarte Beek was carried out. The experiment was carried out from May 1995 to September 1996 at 8 locations along the river Dommel (The Netherlands) and at 3 locations along the Zwarte Beek (Belgium). These 10 locations contain 54 sites in total. Data were collected on ground water levels, groundwater quality, soil moisture quality, soil parameters, N,P & K mineralization, biomass production, nutrient uptake of the vegetation, nutrient limitation, and vegetation composition.

For every site, the average Ellenberg N-indication values were calculated from the vegetation recordings by averaging the Ellenberg indication values of all individual species. Next, linear and quadratic regressions were carried out to determine relationships between average Ellenberg N indication and measured environmental conditions. The results of these regressions are presented in Table 1. The strongest relationship between Ellenberg N indication and an abiotic variable is found for the median NO_3 availability of the upper 10 cm of the topsoil. Less strong relationships are found for net annual N-mineralization and nitrification, and the C/N and C/P ratios of the topsoil. Relationships with availability of PO_4 and K, and with nutrient concentrations in the soil moisture or groundwater are very weak or not significant.

In addition strong relationships are observed for above ground biomass, mainly caused by the above ground biomass production of monocots (grasses, sedges, and rushes). Also the amounts of N, and P taken up by the vegetation show a strong relationship with the average N indication values of Ellenberg. But the strongest relationship is found with the N/P ratio of the phanerogams (higher plants). This indicates that the Ellenberg N-indication should be calibrated with a combination of plant available fractions of N and P. This is in agreement with the results of fertilisation experiments carried out at 6 meadows in the Dommel and Zwarte Beek catchments. Biomass production at two of the 6 sites was N limited but at 4 sites biomass production was limited by combinations of N, P and K (Olde Venterink *et al.* in prep).

The hypothesis that the strongest relationship between Ellenberg N indication values and nutrient availability will be observed with a combination of N and P variables is supported by the result of a multiple quadratic regression. The explained variance (R^2) of this regression between average N indication values and a combination of NO_3 availability and the C/P ratio of the soil is 0.57. Moreover, a similar regression between the N/P ratio in phanerogames and the same environmental variables has a R^2 of 0.72.

For the application of SMART-MOVE in the Dommel catchment however, it is not possible to obtain these two variables (yet). SMART-2 predicts N mineralization and total N availability. The latter variable is determined by the sum of N-mineralization and atmospheric N-deposition (e.g. chapter 2). NO3 availability or C/P ratios are not predicted by SMART-2, and they can also not be determined from other predicted variables. It is therefore most appropriate to obtain the calibration between average N Ellenberg indication and N mineralization (and accept a less strong calibration at this model step). This linear relationship between the two variables is described by the following formula:

Calibration of Ellenberg N-values

$$N_{Ellenberg} = \frac{N_{\min} + 56}{28}$$

$N_{Ellenberg}$	= *average Ellenberg N indication value*	*(-)*
N_{min}	= *net annual N mineralisation*	*(kg N.ha^{-2}.year^{-1})*

Dependent variables	**unit**	**linear**		**quadratic**	
Soil		R^2	*Signif*	R^2	*Signif*
net annual N-mineralization	*mg N/m2.year*	0,33	0,000	**0,35**	0,000
net annual ammonification	*mg N/m2.year*	0,00	0,913		
net annual nitrification	*mg N/m2.year*	0,36	0,000	**0,37**	0,000
net annual P-mineralization	*mg P/m2.year*	0,00	0,945		
net annual K-mineralization	*mg K/m2.year*	0,06	0,086		
median NO3 availability (KCl-extraction)	*mg N/m2*	0,36	0,000	**0,47**	0,000
median NH4 availability (KCl-extraction)	*mg N/m2*	0,01	0,437		
median N-availability (KCl-extraction)	*mg N/m2*	0,25	0,000		
median PO4-availability (lactate/acetate-extraction)	*mg PO4/m2*	0,05	0,110		
median PO4-availability (CaCl-extraction)	*mg PO4/m2*	0,12	0,010		
median K-availability (lactate/acetate-extraction)	*mg K/m2*	0,00	0,856		
median K-availability (CaCl-extraction)	*mg K/m2*	0,00	0,983		
Kjeldahl N soil	*mg N/g dry soil*	0,01	0,494		
Kjeldahl P soil	*mg P/g dry soil*	0,04	0,135		
Kjeldahl K soil	*mg K/g dry soil*	0,01	0,475		
C/N ratio soil		0,01	0,426	**0,35**	0,000
C/P ratio soil		0,09	0,028	**0,36**	0,000
C/K ratio soil		0,15	0,005		
Water					
median NO3 content soil moisture	*mg N/l*	0,22	0,000	0,25	0,001
median NH4 content soil moisture	*mg N/l*	0,06	0,070		
median PO4 content soil moisture	*mg PO4/l*	0,00	0,855		
median K content soil moisture	*mg K/l*	0,01	0,544		
median K content ground water	*mg K/l*	0,02	0,374		
median NH4 content groundwater	*mg N/l*	0,11	0,014	0,23	0,002
median NO3 content groundwater	*mg N/l*	0,03	0,218		
median PO4 content groundwater	*mg PO4/l*	0,05	0,129		
Vegetation					
total above ground biomass	*g/m2*	**0,52**	0,000		
cryptogames biomass	*g/m2*	0,26	0,000		
above ground biomass dicotyls	*g/m2*	0,01	0,493		
above ground biomass monocotyls	*g/m2*	**0,63**	0,000		
above ground biomass phanerogames	*g/m2*	**0,62**	0,000		
ratio cryptogames/phanerogames		0,30	0,000	**0,34**	0,000
ratio dicotyls/monotyls		0,26	0,000	**0,65**	0,000
N content phanerogames	*mg/g*	0,02	0,282	0,16	0,014
P content phanerogames	*mg/g*	0,40	0,000	**0,43**	0,000
K content phanerogames	*mg/g*	0,01	0,523		
N uptake by phanerogames/m2	*g/m2*	**0,61**	0,000		
P uptake by phanerogames/m2	*g/m2*	**0,59**	0,000		
K uptake by phanerogames/m2	*g/m2*	0,29	0,000		
N/P ratio in phanerogames		0,53	0,000	**0,83**	0,000
N/K ratio in phanerogames		0,04	0,173		
K/P ratio in phanerogames		0,28	0,000	**0,36**	0,000

Table 1 Explained variance (R^2) and significance of linear and quadratic regression analysis between the average Ellenberg N indication value of a site (independent variable) and measured soil, water, and vegetation variables (n=54). The sites were located in brook valley meadows in the catchment areas of the Dommel (Ned) and the Zwarte Beek (B). Quadratic regressions are only obtained if the non-linear relationships were significant (P<0.05) and stronger then the linear relationships.

3. SMART2

3.1 The model concept.

To evaluate soil pH and nitrogen availability in response to atmospheric deposition and desiccation in unfertilised systems, de Vries *et al*. (1989) have developed the dynamic soil model SMART (Simulation Model for Acidification's Regional Trends). The original SMART is a one-layer model consisting of a set of mass balance equations describing the soil input-output relationships, and a set of equations describing the rate-limited and equilibrium soil processes. All major ions are included. To minimise the input data requirements for application on a regional scale, some simplifying assumptions have been made. These assumptions, and a detailed overview of the key processes, are described in Kros *et al.* (1995). Because SMART is restricted to dry ecosystems and is not suitable for calculation of N availability, Kros *et al.* (1995) have made some extensions to the original model structure (SMART2). These extensions are: addition of a mass balance for the root zone, inclusion of seepage to the root zone, canopy interactions, litterfal and root decay, N-mineralization, nitrogen uptake by vegetation, and nitrification and denitrification. SMART2 calculations are performed on points. To use SMART2 for regions, the model is imbedded in a geographical information system.

3.2 Input and output

According to Kros *et al.* (1995) input of SMART2 consists of transport of major ions to the root zone from seepage and atmospheric deposition, precipitation and mean spring groundwater levels. Soil chemical processes are calculated for a unique combination of vegetation and soil. This implies that information concerning soil type and vegetation type is crucial. Standard values for soil-vegetation combinations are included in the model. The output of SMART2 consists of soil moisture concentrations of Al^{3+}, Na^{+}, BC^{2+} (Ca^{2+} + Mg^{2+}), K^{+}, $NH4^{+}$, $NO3^{-}$, Cl^{-}, pH, N mineralization and total N availability in the root zone.

3.3 Application of SMART2 in the Dommel catchment

For application within the Dommel catchment, soil data and vegetation data are derived from various sources. For the application of scenario's, mean groundwater levels and information concerning seepage quantity are computed with the Dommel groundwater model (Pieterse, Schot & Verkroost, 1998b).

3.3.1 Soil type

The soil types used by SMART2 are listed in Table 2. To comply for these soil types, the digital soil map of the Netherlands 1:50.000 (de Vries & Denneboom, 1992; Steur & Heijink, 1991) and the digitized soil map of Belgium 1:20.000 (Baeyens, 1976) are used. The conversion of the soil map of the Netherlands to the soil types in Table 2 is described in Kros *et al*, (1995). Associations of soil types are converted according to the first soil code in the association. Appendix 1 lists the conversion scheme for Belgian soil types to SMART soil codes. This conversion is based upon the textural characteristics of the Belgian soil types. Soils with the code 'V' , soils with a peat top layer, and soils with a peat layer in the upper 50 cm are converted to soil type PN. Rich sand types (SR) are derived from loamy texture codes 'S' and 'L' (assumed to be comparable with .23 soil codes of the Dutch soil map). Poor sand (SP) types are derived from sandy soil codes 'Z'. Presence of calcium in the soil could not be distinguished from the Belgian codes. But when considering the geochemical characteristics of shallow groundwater in the Belgian part of the catchment (Table 7) it is not likely that calcareous soil types exist in the Dommel catchment part of the Kempian plateau. Clay and Löss soil types were not present in the Belgian part of the catchment. Appendix 1 is a map of the soil types, classified into SMART2 codes, in the Dommel catchment.

Code	Soil class	Common soil types
SP	Sand Poor	Carbic Podzols, Arenosols
SR	Sand Rich	Gleyic Podzols, Gleysols
SC	Sand Calcareous	Arenosols
CN	Clay Non-Calcareous	Fluvisols
CC	Clay Calcareous	Fluvisols
LN	Löss Non-Calcareous	Luvisols
PN	Peat Non-Calcareous	Histosols

Table 2: Soil types used in SMART2. Source: (Kros et al., 1995).

3.3.2 Vegetation types

Dutch part of the catchment area

The vegetation types used as input for SMART2 are listed in Table 3. To comply for these vegetation types, the LGN2 survey of the Netherlands (Thunnissen *et al*., 1992) was used to discriminate urban area and farmland from extensively used land (deciduous forests, coniferous forests, heather and extensive grassland). Because the LGN2 survey does not distinguish extensively used grassland, the vegetation inventory of the province of North Brabant was used for mapping of extensive grassland and heather. For this purpose, the greater part of the provincial vegetation inventory had to be digitized. For the Dutch part of the Dommel catchment, the vegetation types PIN and SPR could not be distinguished. It is assumed that *Pinus Sylvestrus* is the dominating coniferous species. Translation of provincial vegetation types to SMART2 vegetation types is listed in appendix 2.

Belgian part of the catchment area

For the Belgian part of the catchment, the national inventory and evaluation of the vegetation of Belgium, or BWK de Blust *et al.* (1985) is used. This survey not only distinguishes the main vegetation classes (deciduous forest, coniferous forest, extensive grassland, heather, farmland, urban area), but also distinguishes within these main classes on the base of plant species occurences. Appendix 2 gives an overview of the BWK types and the transformation to SMART2 vegetation classes.

Code	Vegetation class	Common species
PIN	Pine forest	Scots pine and black pine. Evergreen trees with: moderate forest filtering, growth rate and transpiration rate
SPR	Spruce forest.	Douglas fir, Norway spruce. Evergreen trees with: high forest filtering, growth rate and transpiration rate
DEC	Deciduous forest	Oak, Beech, Japanese larch. Needle or leave sheddy trees with: low forest filtering, growth rate and transpiration rate
HEA	Heather	Calluna, Erica
GRP	(Nutrient poor) grassland	Common grass species, no fertilisation or grazing

Table 3: Vegetation types in SMART2. Source: (Kros et al., 1995).

3.3.3 Spring water levels

In the nature planner (Latour *et al*., 1997), actual mean spring water levels are derived from water table class information of the soil map using the empirical formula of van der Sluijs (1990, in Kros *et al*., 1995). The mean spring water level is corrected with LGM computations for the year 1988.

In the Dommel catchment, mean spring groundwater levels are assumed to be related to mean annual groundwater levels calculated with the Dommel groundwater model (Pieterse *et al.*, 1998). The estimated mean annual groundwater levels are translated to mean spring groundwater levels using measured groundwater levels in the period October 1995 - September 1997. This transformation is performed as a linear regression (R^2 of 0.98).

Transformation between average yearly- and average spring water levels

$$MSL = -9.3 + 1.01 * MAL$$

MSL = *Mean spring groundwater level below surface level* *(cm)*
MAL = *Mean annual groundwater level below surface level* *(cm)*

3.3.4 Seepage

The amount of seepage is defined as the upward movement of groundwater to the root zone. This groundwater flow is calculated with a groundwater model of the Dommel catchment (Pieterse *et al*., 1998b).

SMART2 uses 5 groundwater types with chemical characteristics derived from van Wirdum, (1991). The hydrochemical characteristics of these types are listed in Table 4 and Table 5.

LKN type	**Application**	**van Wirdum type**
LKN 0:	No seepage	Mixed water: 50% relatively Ca-rich groundwater + 50% precipitation water, relatively unpolluted.
LKN 1	Seepage	identical to LKN 0
LKN 2	Seepage	Groundwater, 100% relatively Ca-rich groundwater
LKN 3	Seepage	Brackish water: 10 % water from the North Sea + 90% precipitation (relatively unpolluted)
LKN 4	Seepage	Sea water, 100% water from the North Sea.

Table 4: LKN types and chemical characteristics according to (van Wirdum, 1991), Source: (Kros et al., 1995).

LKN type	**SO_4^{2-}**	**NO_3^-**	**NH_4^+**	**BC^{2+}**	**K^+**	**NA^+**	**CL^-**
LKN 0	0.20	0.06	0.05	3.23	0.03	0.30	0.20
LKN 1	0.20	0.06	0.05	3.23	0.03	0.30	0.20
LKN 2	0.27	0.02	0.04	6.42	0.05	0.52	0.31
LKN 3	5.74	0.02	0.12	19.50	1.05	46.00	54.10
LKN 4	55.00	0.02	0.78	137.70	10.00	456.00	538.00

Table 5: Groundwater concentrations for the LKN types used in SMART2 (eq / m^3). Source: Kros et al. (1995). $BC^{2+} = Ca^{2+} + Mg^{2+}$

From a comprehensive data set of 180 groundwater-sampling tubes at 129 locations in the study area, 45 groundwater-sampling tubes were selected representing seepage areas in the river valley. Only groundwater tubes with filters deeper than 2 meters below surface level were obtained. Groundwater samples are taken 8 to 14 times between October 1995 and September 1997 and analysed on all major ions. The results are presented in Table 7.

Code	**Description of the location**
Do	Dommelbeemden (near St Oedenrode)
Eh	Elshouters (near Waalre)
Sp	't Spekt (near Son en Breughel)
Uz	Urkhovense Zeggen (between Eindhoven and Nuenen)
Zw	Zwarte Beek (at the Kempian Plateau, near Leopoldsburg)
Ne	Neerhoksent (At the Kempian plateau, near Hechtel-Eksel)

Table 6: Codes of the fieldwork locations. A map of these locations is presented in appendix 4

	n-loc	**n-samp**	**pH**	**EC**	**SO_4^{2-}**	**NO_3^-**	**NH_4^+**	**BC^{2+}**	**K^+**	**NA^+**	**CL^-**
Do	15	132	6.45	536	1.481	0.009	0.023	3.577	0.106	1.054	1.268
Eh	9	95	6.51	277	0.136	0.004	0.037	2.067	0.039	0.390	0.403
Sp	1	4	6.82	614	0.704	0.007	0.022	5.051	0.036	1.034	0.939
Uz	10	79	6.83	232	0.030	0.006	0.021	1.998	0.029	0.436	0.437
Zw	5	39	6.28	133	0.079	0.004	0.020	1.102	0.044	0.139	0.138
Ne	11	72	6.10	248	0.522	0.019	0.013	1.490	0.065	0.349	0.510

Table 7: Median concentrations of major ions sampled from 6 river valley locations in the Dommel catchment (eq / m^3). n-loc indicates the number of tubes used at this location, n-samp indicates the number of samples collected during the sampling period. EC is the electric conductance in mS/cm. Samples are taken between oktober 1995 and september 1997.

Table 7 shows that SO_4^{2-}, K^+, Na^+ and Cl^- concentrations are fairly similar to the LKN types 0, 1 and 2. At locations with considerable human influence, the Dommelbeemden, Spekt and Neerhoksent, show somewhat higher concentrations relative to LKN 0, 1 and 2. This corresponds with observations by Stuurman (Stuurman & Pakes, 1991; Stuurman *et al*., 1990; Stuurman & van der Weg, 1993) who recognise a human-influenced zone up to 60 m below elevation level, although NO_3^- and NH_4^+ concentrations are remarkable low. BC^{2+} concentrations on the Kempian plateau are 50% of the LKN type 0. These low BC^{2+} concentrations can also be found in the Dutch part of the catchment, south from Eindhoven (locations Eh and Uz). Locations north from Eindhoven (locations Do and Sp) show BC^{2+} concentrations matching the LKN 1 type.

Because the low BC^{2+} concentrations on the Kempian plateau are considered to be typical for the Kempian plateau (e.g. Aggenbach *et al*., 1990), a new SMART-seepage type is introduced for the Dommel catchment (see Table 8, *DOM1*). This seepage type has a BC^{2+} concentration of 1.8 eq / m^3. All other ions of the Kempian seepage type are kept identical to LKN 1. SMART2 calculations will be carried out with the DOM1 seepage type.

LKN type	SO_4^{2-}	NO_3^-	NH_4^+	BC^{2+}	K^+	NA^+	CL^-
DOM 1	0.20	0.06	0.05	**1.8**	0.03	0.30	0.20

Table 8: SMART2 seepage type for the Kempian plateau. This type is identical to LKN 1 (Kros et al., 1995) except for BC^{2+} concentrations. Concentrations are in eq / m^3.

3.3.5 Atmospheric deposition

SMART2 uses atmospheric deposition values of the ions: SO_x, NO_x, NH_y, Na, K, Ca, Mg and Cl, and annual precipitation rates. Evapotranspiration rates are included in the properties of unique soil-vegetation combinations.

During preliminary simulations, it became clear that SMART2 simulations needed an iteration period of at least 40 years to reach a stable simulation of acidity and N-mineralization. To comply with this need, environmental balance calculations are performed for the period 1950 - 1996. Table 9 lists the average deposition rates for the Dommel catchment from 1981 - 1996 in the Dommel catchment. Deposition rates during the period 1950 – 1980 are regarded identical to the deposition of 1981. Deposition of Na, K, Ca, Mg and Cl is assumed to be constant during the simulation period.

Year	SO_x [1]	NO_x [1]	NH_y [1]	Na [1]	Cl [1]	K [1]	Ca [1]	Mg [1]	Prec [2]
1980	2487	932	2817	450	450	55	110	80	742
1981	2487	932	2867	450	450	55	110	80	852
1982	2159	915	2898	450	450	55	110	80	708
1983	1917	933	2882	450	450	55	110	80	763
1984	2047	932	2945	450	450	55	110	80	818
1985	2185	900	3081	450	450	55	110	80	811
1986	1822	843	2830	450	450	55	110	80	841
1987	1569	895	3215	450	450	55	110	80	846 [3]
1988	1164	786	2818	450	450	55	110	80	742 [3]
1989	1017	793	2860	450	450	55	110	80	753 [3]
1990	1010	769	2857	450	450	55	110	80	675
1991	925	734	2750	450	450	55	110	80	648
1992	931	789	2564	450	450	55	110	80	826
1993	922	779	2551	450	450	55	110	80	862
1994	814	861	2237	450	450	55	110	80	894
1995	680	790	2149	450	450	55	110	80	773
1996	600	835	2400	450	450	55	110	80	632

Table 9: Estimated average atmospheric deposition in the Dommel catchment area (Source: RIVM, unpublished). [1] Concentrations are in eq / ha / year. [2] Precipitation(mm) is derived from weather station Gemert (near Eindhoven). [3] Precipitation values for 1987 - 1989 are estimated using values of de Bilt.

3.3.4 Application of SMART

Smart calculations are carried out separately for the grassland prediction model MOVE and the alder forest prediction model ALNION (Olde Venterink *et al*., 1998). For both models the existing land use in the catchment is replaced with the overall SMART2 vegetation type for each prediction model (extensive grassland and deciduous forest res.). Hence, the assumption is made that the long-term effects of present-day land use are expired, or will be taken care of.

During SMART2 test simulations it became clear that the simulated acidity of sandy soils only matches observations when the spring groundwater level is below 15 cm. Simulations on sites with a spring groundwater level varying between 0 and 15 cm are unrealistically high. Therefore, sites that have a MSL between 0 – 15 cm is given the value of 15 cm. Further, the simulated acidity of peat soils is much too low if only groundwater seepage is used as groundwater flow input for SMART2. It is therefore assumed that capillary rise in peat soils contributes to the pH value of peat soils. For SMART2 simulations in peat soils, capillary rise is added to groundwater seepage, calculated with a water balance model for the phreatic zone by Pieterse *et al*., (1998a).

The level of detail of simulation of groundwater levels and seepage in the Dommel catchment is of 500 meter gridcells. Differentiation within these gridcells is possible because the soil map and elevation map have a higher level of detail. Assuming the variance of groundwater levels within a 500 meter cell depends on the variance of the surface elevation, a cellsize of 100 meter is applied.

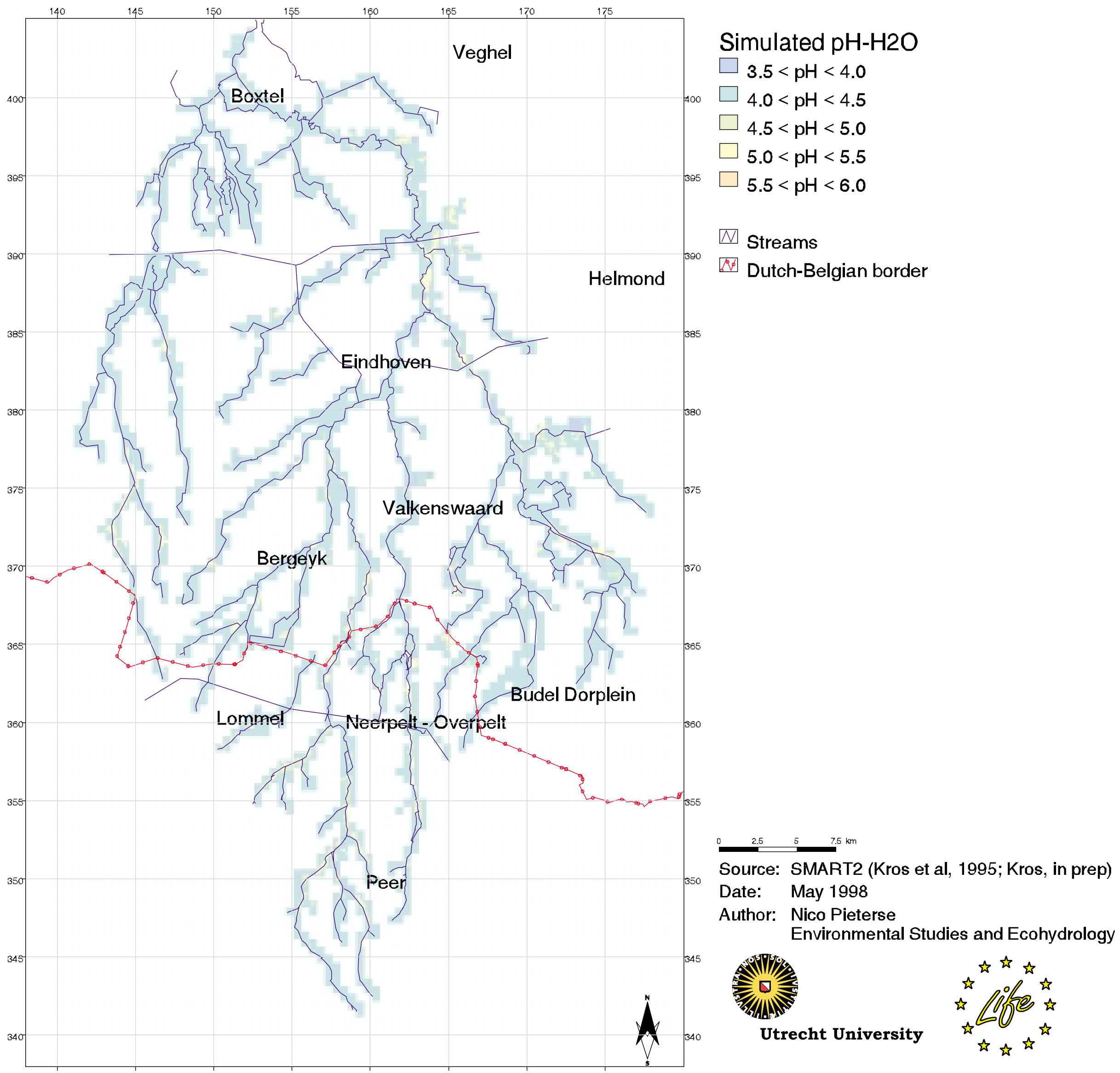
In Table 10 a comparison is made between simulated and observed acidity and N-mineralization for several locations in the study area. Within the Dommel catchment pH-KCL of the topsoil is measured 8 times during 1995- 1996 at 32 extensive grassland locations. N-mineralization is measured during 1995 – 1996 for the same 32 locations. To compare the calculated and measured pH, regression between pH-SMART and pH-KCl was applied. According to Kros (in prep) pH-SMART represents the ‘real’ pH of the root zone, closely reflecting the pH of the soil moisture. Kros fitted the pH of soil moisture samples with pH-KCl (Kros, in prep). MOVE uses the pH-H_2O of the topsoil, obtained with regression between pH-SMART and pH-H_2O (Kros, in prep).

			pH-KCl				**N-Mineralization (kg N ha^{-1} year^{-1})**			
			Observed			**Simulated**	**Observed ***			**Simulated ****
LOC	**n**	**Soil type**	**Min**	**Max**	**Median**		**Min**	**Max**	**Median**	
SH	*2*	*Sand*	3.7	3.8	3.8	3.6	19	35	27	99
EH	*3*	*Sand*	4.2	4.2	4.2	3.7	112	167	113	92
SP	*3*	*Sand*	4.5	5.1	5.0	4.0	25	109	49	98
UZ	*4*	*Sand*	3.7	4.8	4.5	4.0	23	199	65	100
UZ	*2*	*peat*	4.4	4.8	4.6	4.8	64	84	74	98
DO	*15*	*peat*	4.0	4.8	4.4	5.0	15	272	89	130
RV	*3*	*peat*	4.1	4.7	4.3	4.6	16	38	31	98

*Table 10: Calculated and observed pH-KCl and N-mineralization for grassland locations within the Dommelcatchment. pH-KCL is converted from pH-SMART with regressions found by Kros (in prep.). * Net mineralization (= mineralization – denitrification) of the top soil (10 cm),*
*** Mineralization of litter and roots in the top soil (20 cm)*
SH = Strijper Heg, EH = Elshouters, UZ = Urkhovense zeggen, DO = Dommelbeemden, RV = Rietvelden, SP = ‘t Spekt, n = number of sites.

From the comparison between simulated and observed acidity is concluded that the pH simulations for extensive grasslands reflect field observations. The simulated acidity for the location ‘t Spekt (SP) is too low, which can be accredited to a local calcareous–rich topsoil. Results of SMART2 pH calculations are shown in figure 5.

N-mineralization simulations for extensive grasslands do not match with median observations (Table 10). This is expected, since the methods used to assess N-mineralization are not equal. SMART2 calculates N-mineralization of litter and dead roots, which is usual for forests. Observed N-mineralization is measured according to the standard method for grassland ecosystems (soil incubation method, Raison *et al*, (1987); Berendse *et al*., (1994); Olff *et al*, (1994)). However, a correlation between simulations and observations could be expected. Table 10 shows that this correlation does not exist. Moreover it also shows that simulated N-mineralization hardly differentiates between various sites, although these sites have different soil properties and different hydrological regimes. Therefore it is concluded that the nutrient-availability (N) variable in the MOVE response equations cannot be assessed with the model SMART2. The nutrient-availability variable is excluded from the vegetation response equations. This is carried out by applying the optimum N-value for each processed plant species.



Source: SMART2 (Kros et al, 1995; Kros, in prep)
Date: May 1998
Author: Nico Pieterse
Environmental Studies and Ecohydrology

Utrecht University

Figure 5: Simulated pH-H_2O in the Dommel catchment area. Simulations are performed with SMART2 (Kros et al., 1995).

4. Observed and simulated grassland types in the Dommel catchment.

In this chapter, model simulations of SMART-MOVE are compared with an inventory of grasslands and fens in the catchment area of the river Dommel (Belgium/The Netherlands). For this purpose groups of characteristic species were selected for the most important grassland and fen types of lowland brook valleys. This selection is based on Schaminee *et al* (1995; 1996), except for species of the *Filipendulion* which are based on Den Held (1991).

For the inventory of observed grasslands and fens in the Dommel catchment, vegetation maps are used. The inventory in the the Belgian part of the catchment is carried out in the first half of the 1980's, as part of the national inventory of the vegetation of Belgium: BWK (e.g. de Blust et al, 1985). The inventory of the Dutch part of the catchment is carried out between 1989 and 1991, as part of the vegetation inventory of the province of North Brabant, The Netherlands: PMI (e.g. Anonymous, 1990).

The classification of vegetation types used in the BWK inventory is similar to the vegetation types used in this report. Only the vegetation types *Alopecurion pratensis* and *Lolio-Potentillion anserinae* are missing in the BWK classification (e.g. Table 11). The PMI vegetation types had to be translated, which was complicated. The PMI classification is based on a clustering of vegetation releveés. Besides the well-developed vegetation types shown in Table 11, a number of degraded types, of for instance *Junco-Molinion* (PMI 602) and *Calthion palustris* (PMI 605), are found in the PMI data-set. These degraded types are omitted because the characteristic species, on which the model simulations are based, are absent.

	Nar Gal	***Jun Mol***	***Cal Pal***	***Alo pra***	***Arr ela***	***Cyn cri***	***Lol Pot***	***Fil***	***Car nig***	***Car gra***	***Phr***
BWK	Hn Ho Hmo	Hm Hmm	Hc	-	Hu	Hp Hr	-	Hf Hj	Ms	Mc	Mr
PMI	614	601	605	-	612 (610) (611)	(610) (611)	215 216 507 508 509 607	201 604	-	204 207 218	200 202 203 206 208 209 211 213 214 221

Table 11 Classification of vegetation types in the vegetation inventory of Belgium (BWK) and The Netherlands (PMI). BWK is based on the national inventory and evaluation of the vegetation of Belgium (de Blust et al, 1985). PMI is based on the vegetation inventory in the province of N-Brabant, The Netherlands (Anonymus, 1990). Nar Gal: Nardo-Galion saxatilis; Jun Mol: Junco-Molinion; Cal pal: Calthion palustris; Alo pra: Alopecurion pratensis; Arr ela: Arrhenaterion elatioris; Cyn cri: Cynosurion cristati; Lol Pot: Lolio-Potentillion anserinae; Fil: Filipendulion; Car nig: Caricion nigrae; Car gra: Caricion gracilis/Caricion elatae; Phr: Phragmitetea.

A map of the inventory of grasslands and fens in the Dommel catchment is shown in figure 6 – 10. In addition, the frequency of occurrence of each of the grassland vegetation types is presented in Table 12. It is remarkable that *Cynosurion cristati* is the only regularly observed vegetation type, and is only found in the Belgian part of the catchment. *Cynosurion cristati* is a relative nutrient-rich, extensively used grassland type. This is supported by field observations during 1995 – 1996: most grasslands in the Belgian part of the catchment are extensively grazed by cattle, whereas in the Dutch part of the catchment almost all grasslands are intensively use for agriculture, heavily fertilized and cultivated. From the remaining grassland types is only *Lolio-Potentillion anserinae* not rare, probably because this type is also relatively nutrient-rich, extensively grazed by cattle and is flooded regularly. The occurrence of other grasslands or fens is marginal and restricted to small nature reserves. In the Belgian part of the catchment, the wet and relatively eutrophic types *Filipendulion* and *Phragmitetea* are found in some parts of the brook valleys. The other more species-rich vegetation types are very rare or absent. Because almost all vegetation types that are important from the point of view of nature conservation and restoration are absent or extremely rare in the catchment, a validation of simulations was not carried out.

	Nar Gal	***Jun Mol***	***Cal pal***	***Alo Pra***	***Arr ela***	***Cyn cri***	***Lol Pot***	***Fil***	***Car Nig***	***Car Gra***	***Phr***
Dutch Part	3	17	93	-	5	-	892	70	-	25	121
Belgian Part	0	0	22	-	84	14366	-	302	3	2	285
Total	3	17	115	-	89	14366	892	372	3	27	406

Table 12: Observations of different extensively used grasslands and fens in the Dommel catchment. Every count represents a cell of 50 meters wide. Nar Gal: Nardo-Galion saxatilis; Jun Mol: Junco-Molinion; Cal pal; Calthion palustris; Alo pra: Alopecurion pratensis; Arr ela: Arrhenaterion elatioris; Cyn cri: Cynosurion cristati; Lol Pot: Lolio-Potentillion anserinae; Fil: Filipendulion; Car nig: Caricion nigrae; Car gra: Caricion gracilis/Caricion elatae; Phr: Phragmitetea.

The response of vegetation types is simulated with SMART-MOVE according to the method described in paragraph 2.1. The probability of occurrence of the vegetation types is simulated at a resolution of 100 meter. For visualisation, the results are aggregated to a 500-meter grid. To get the maximum probability of occurrence of each vegetation type, the highest simulated probability of occurrence of one of the 25 100-meter cells is assigned to the aggregated cell. Note that model simulations show the probability of occurrence of meadows and fens, if land use would ‘allow’ these vegetation types to occur.

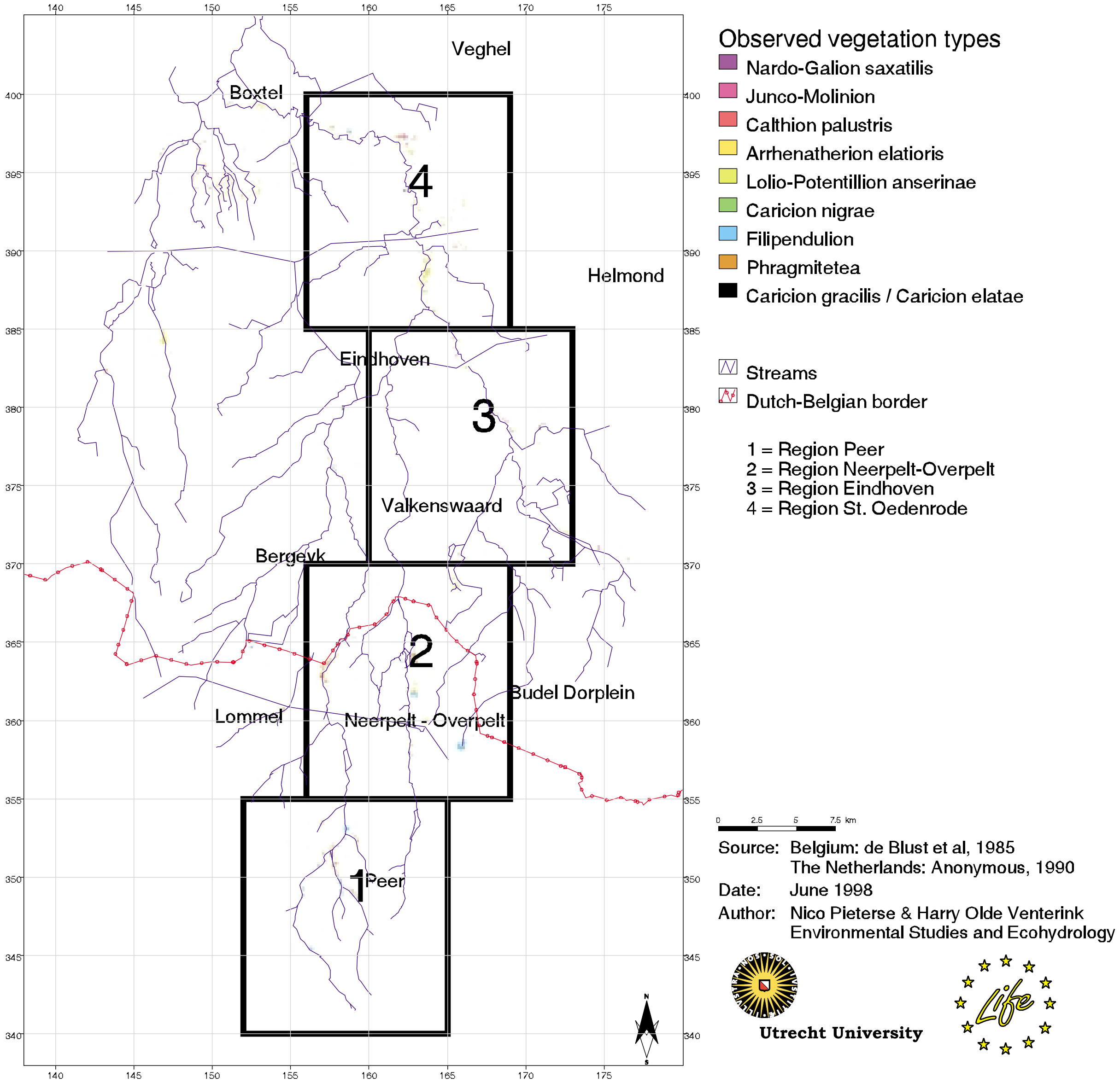
	Nar Gal	***Jun Mol***	***Cal pal***	***Alo Pra***	***Arr ela***	***Cyn cri***	***Lol Pot***	***Fil***	***Car nig***	***Car gra***	***Phr***
n	10	15	13	9	19	12	10	13	8	16	11
Pmax	0.50	0.55	0.41	0.35	0 31	0.40	0.32	0.30	0.29	0.39	0.39
OPTN	2.0	2.7	3.8	4.6	4.2	4.6	5.7	4.9	3.7	4.9	5.7
OPTR	3.8	5.1	5.3	5.8	6.7	5.9	6.8	5.9	4.6	5.9	6.4
OPTF	6.2	7.2	7.4	6.1	4.7	5.7	6.8	8.1	8.6	8.6	9.4

Table 13: Maximum probability of occurrence (Pmax) and optimum indication values of several vegetation types. The maximum probability of a vegetation type is the average probability of occurrence of all characteristic species, listed in appendix 3. n = the number of characteristic species, OPT(N,R,F) = optimum Ellenberg indication value. Nar Gal: Nardo-Galion saxatilis; Jun Mol: Junco-Molinion; Cal pal: Calthion palustris; Alo pra: Alopecurion pratensis; Arr ela: Arrhenaterion elatioris; Cyn cri: Cynosurion cristati; Lol Pot: Lolio-Potentillion anserinae; Fil: Filipendulion; Car nig: Caricion nigrae; Car gra: Caricion gracilis/Caricion elatae; Phr: Phragmitetea.

Figure 11 to Figure 17 show the distribution of the probability of occurrence greater than 0.1 (P > 0.1) for 7 selected vegetation types. As a reference for the simulations, the maximum probability of occurrence of all vegetation types is presented Table 13.

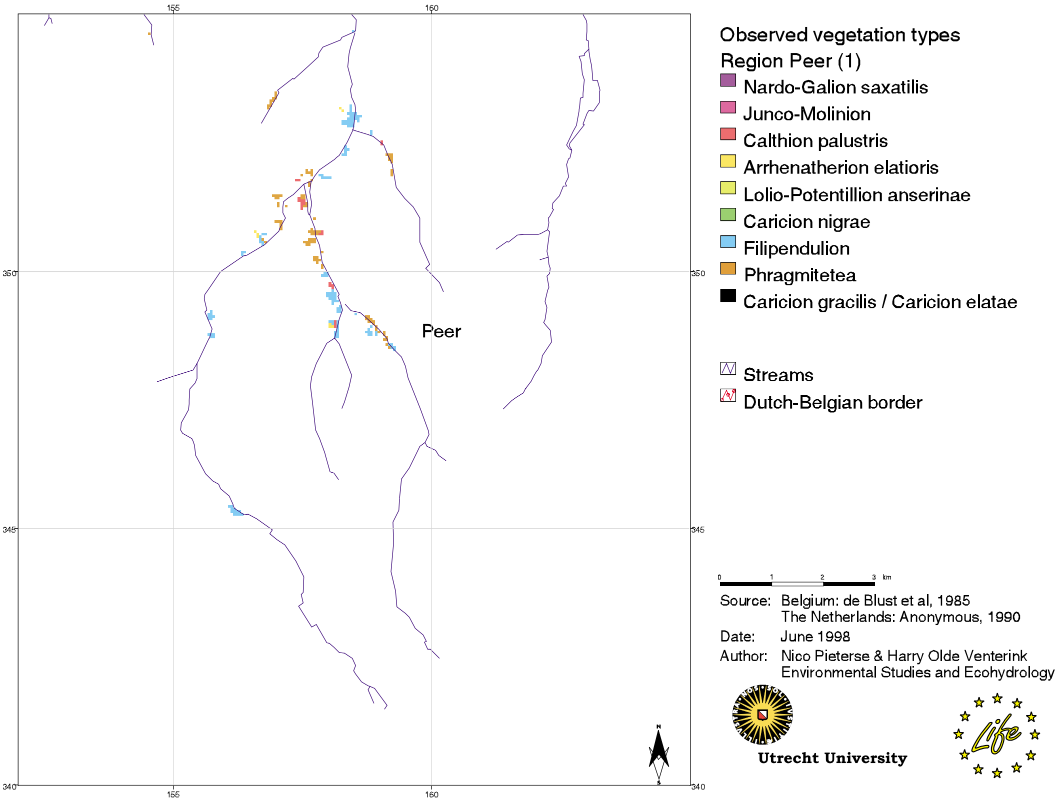
Vegetation types for wet habitat conditions (*Junco-Molinion, Calthion palustris, Caricion nigrae, Caricion gracilis/elatae,* and *Filipendulion*) have a relative high probability of occurrence in brook valleys along the main stream of the Dommel in the Belgian part of the catchment and near the Belgian/Dutch border, along the Strijper Aa, the Kleine Dommel, and along a part of the Beerze. For names of streams is referred to Appendix 4. Of these vegetation types, the types *Calthion palustris* and to a lesser extend *Junco Molinion* have the highest simulated probability of occurrence. The area of *Junco Molinion* where P > 0.1 is larger than for *Calthion palustris*. The simulated probability of occurrence of the other 'wet' vegetation types is low (P < 0.2).

N availability could not be included in the MOVE simulations, but has to be taken into account for interpretation of the results. From Table 13 can be concluded that the simulated probability of occurrence for *Junco Molinion* is probably overestimated. This vegetation type only occurs at oligotrophic sites, which are rare in the Dommel catchment. Moreover, reclaiming agricultural land for restoration of oligotrophic grasslands can be very difficult due to the large amount of nutrients stored in the topsoil. Vegetation types for wet eutrophic sites, like *Filipendulion and Caricion gracilis/Caricion elatae*, are more likely to occur under these circumstances. Finally, the simulation of the probability of the *Cynosurion cristati* is only at a few sites higher than 0.2. This vegetation type is the common grassland in the Belgian part of the catchment. The difference between simulation and observation is most likely caused by the fact that in reality grasslands of this vegetation type are extensively fertilized (e.g. Schaminee, et al, 1996). This impact of fertilizer is not obtained in the model.



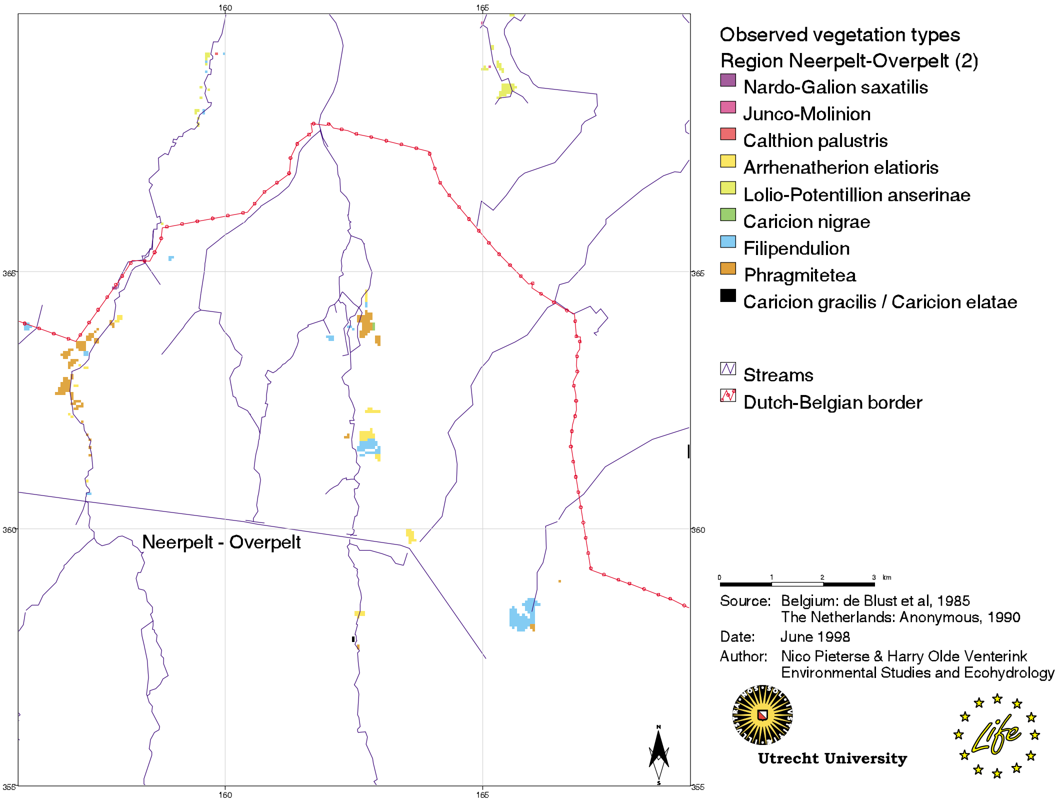
Source: Belgium: de Blust et al, 1985
The Netherlands: Anonymous, 1990
Date: June 1998
Author: Nico Pieterse & Harry Olde Venterink
Environmental Studies and Ecohydrology

Figure 6 Map with observed vegetation types in the Dommel catchment. Source: de Blust et al. (1985); Anonymous (1990).



Source: Belgium: de Blust et al, 1985
The Netherlands: Anonymous, 1990
Date: June 1998
Author: Nico Pieterse & Harry Olde Venterink
Environmental Studies and Ecohydrology

Figure 7 Map with observed vegetation types in the Dommel catchment, region Peer. Source: de Blust et al. (1985); Anonymous (1990).



Source: Belgium: de Blust et al, 1985
The Netherlands: Anonymous, 1990
Date: June 1998
Author: Nico Pieterse & Harry Olde Venterink
Environmental Studies and Ecohydrology

Figure 8 Map with observed vegetation types in the Dommel catchment, region Neerpelt-Overpelt. Source: de Blust et al. (1985); Anonymous (1990).

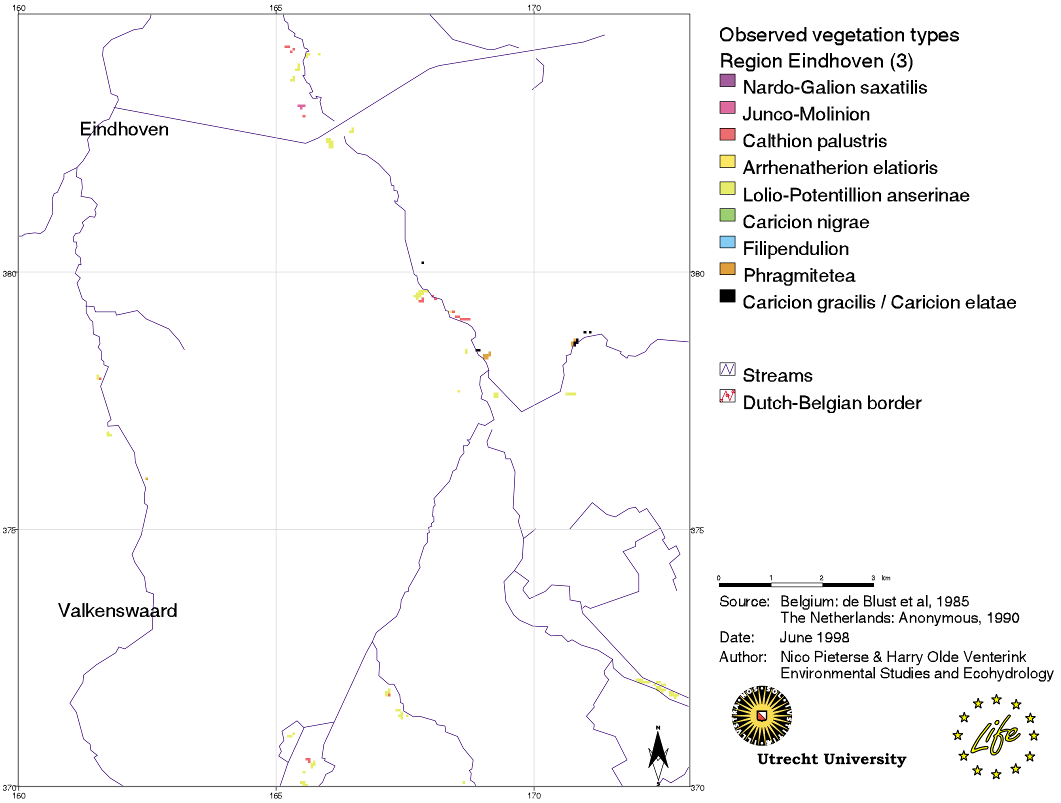


Figure 9 Map with observed vegetation types in the Dommel catchment, region Eindhoven. Source: de Blust et al. (1985); Anonymous (1990).

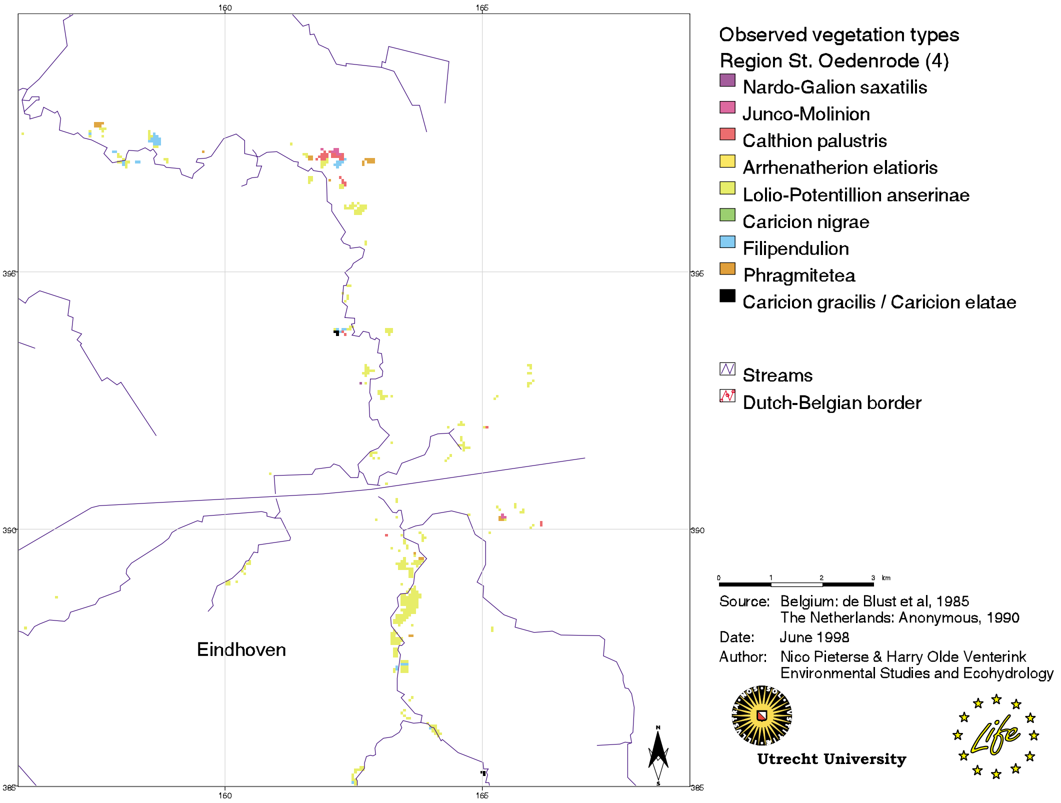


Figure 10 Map with observed vegetation types in the Dommel catchment, region St. Oedenrode. Source: de Blust et al. (1985); Anonymous (1990).

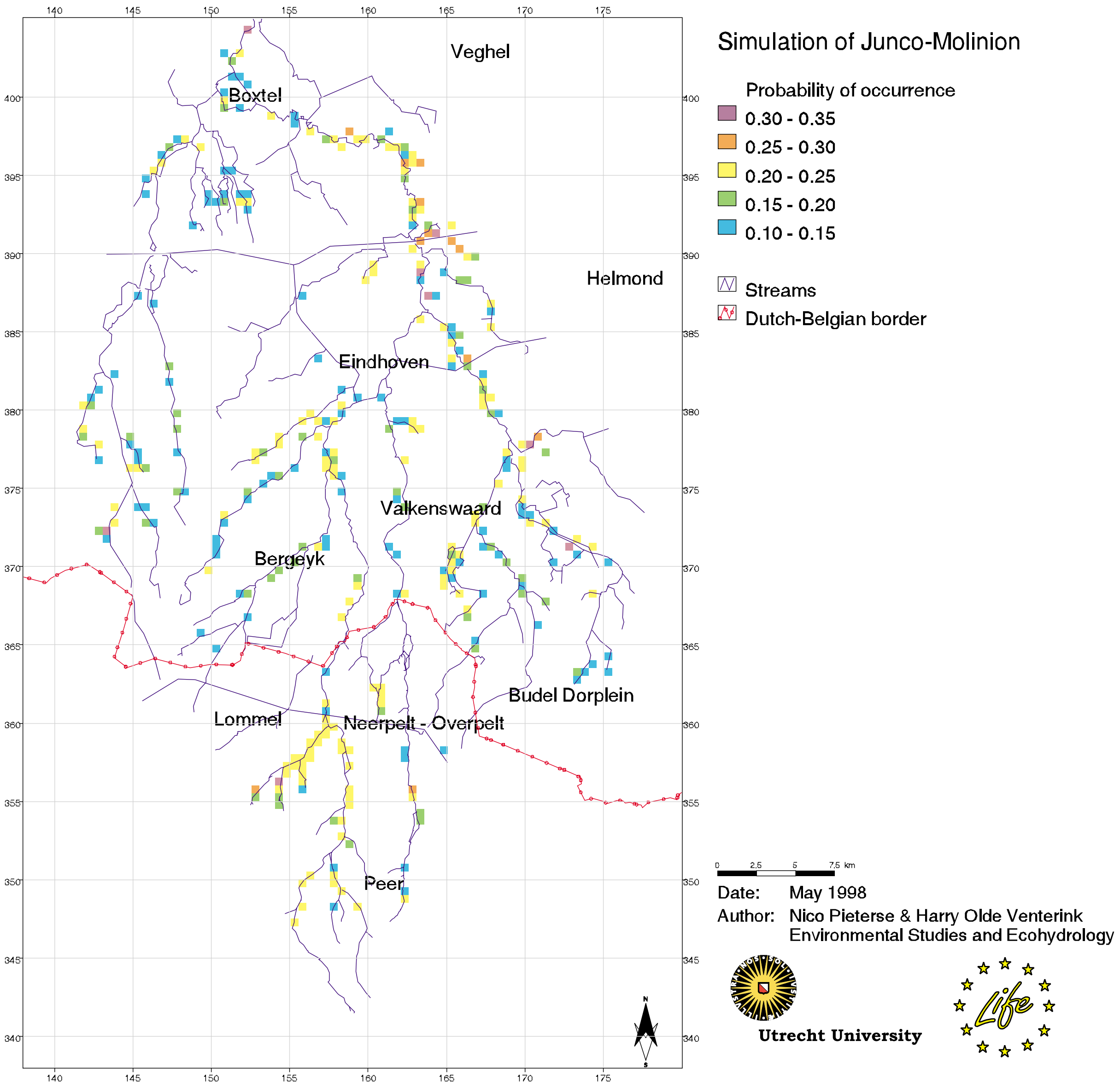


*Figure 11 Map with the probability of occurrence of the vegetation type **Junco-Molinion** in the Dommel catchment.*

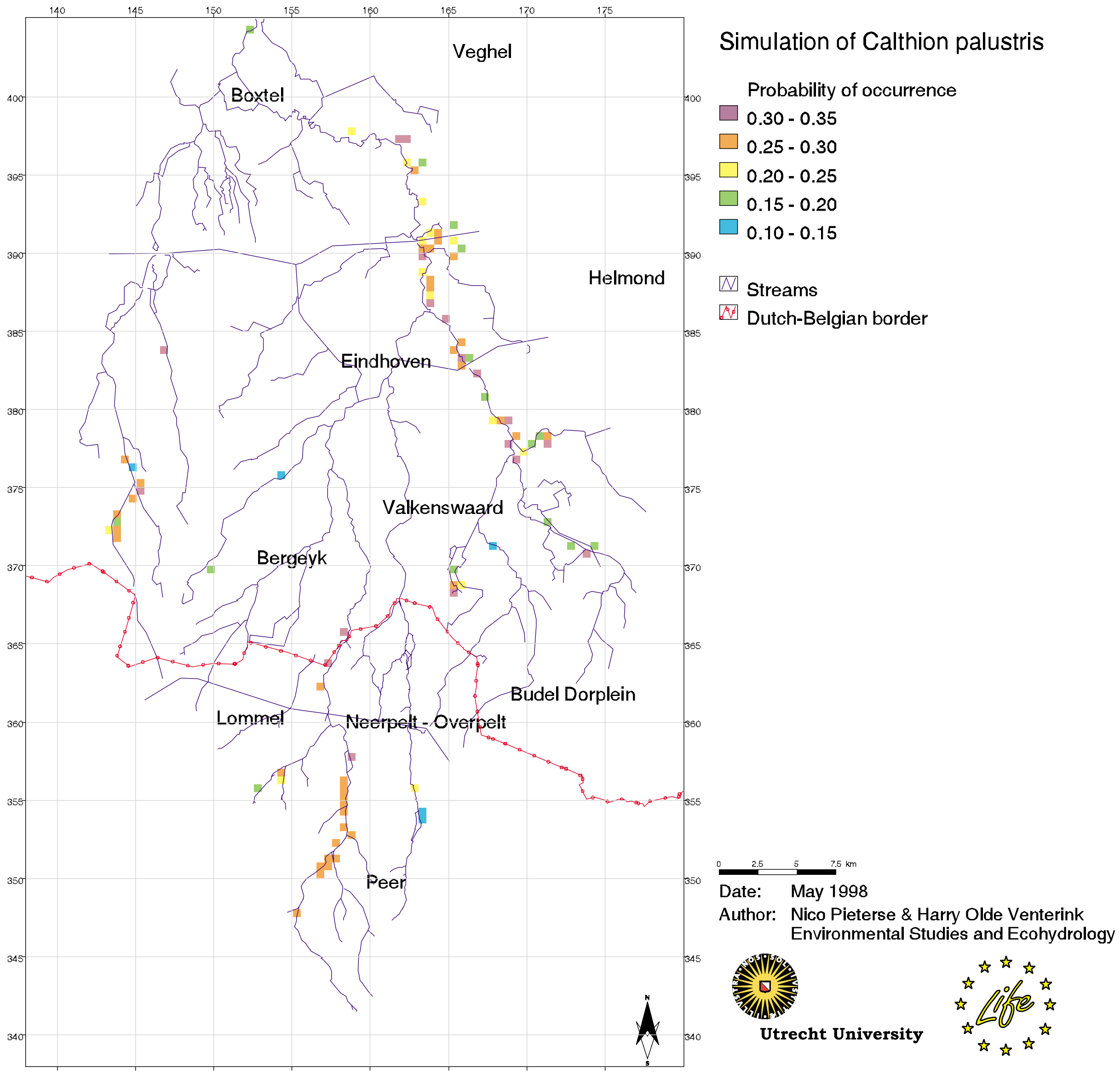
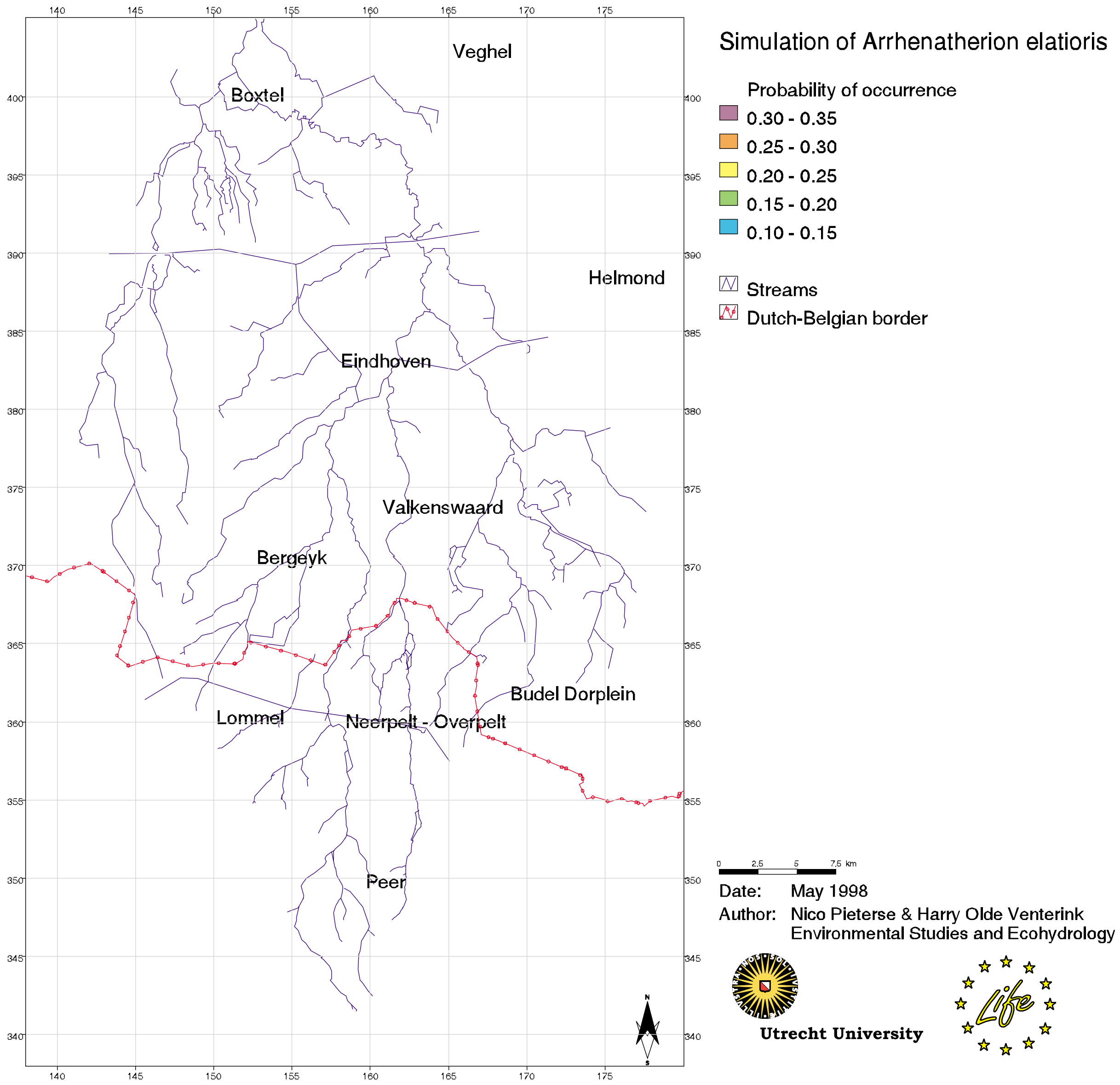


*Figure 12 Map with the probability of occurrence of the vegetation type **Calthion Palustris** in the Dommel catchment.*



Simulation of Arrhenatherion elatioris

Probability of occurrence
🟪 0.30 - 0.35
🟧 0.25 - 0.30
🟨 0.20 - 0.25
🟩 0.15 - 0.20
🟦 0.10 - 0.15

Streams
Dutch-Belgian border

Date: May 1998
Author: Nico Pieterse & Harry Olde Venterink
Environmental Studies and Ecohydrology

Utrecht University

Figure 13 Map with the probability of occurrence of the vegetation type ***Arrhenatherion elatioris*** *in the Dommel catchment.*

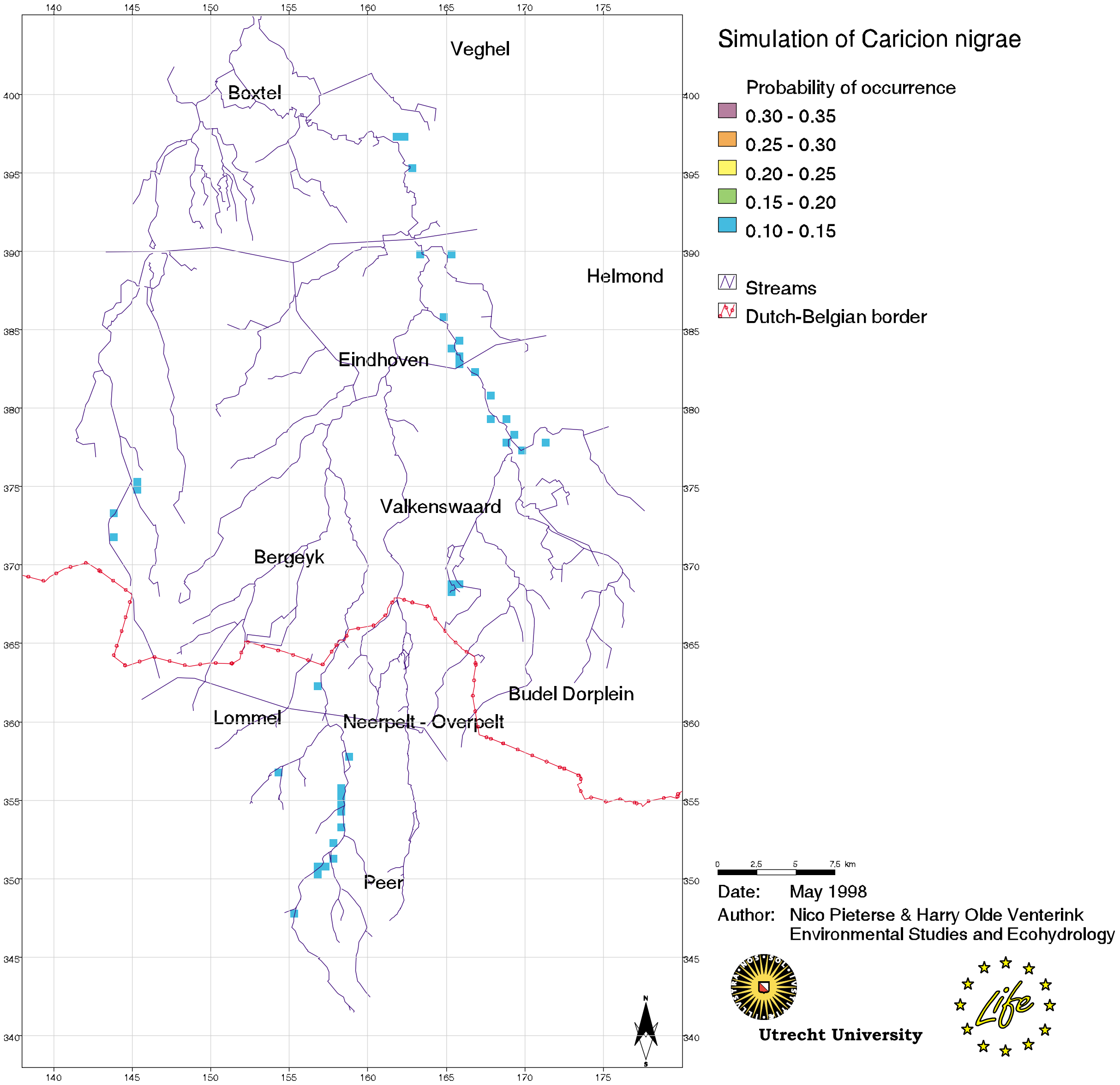
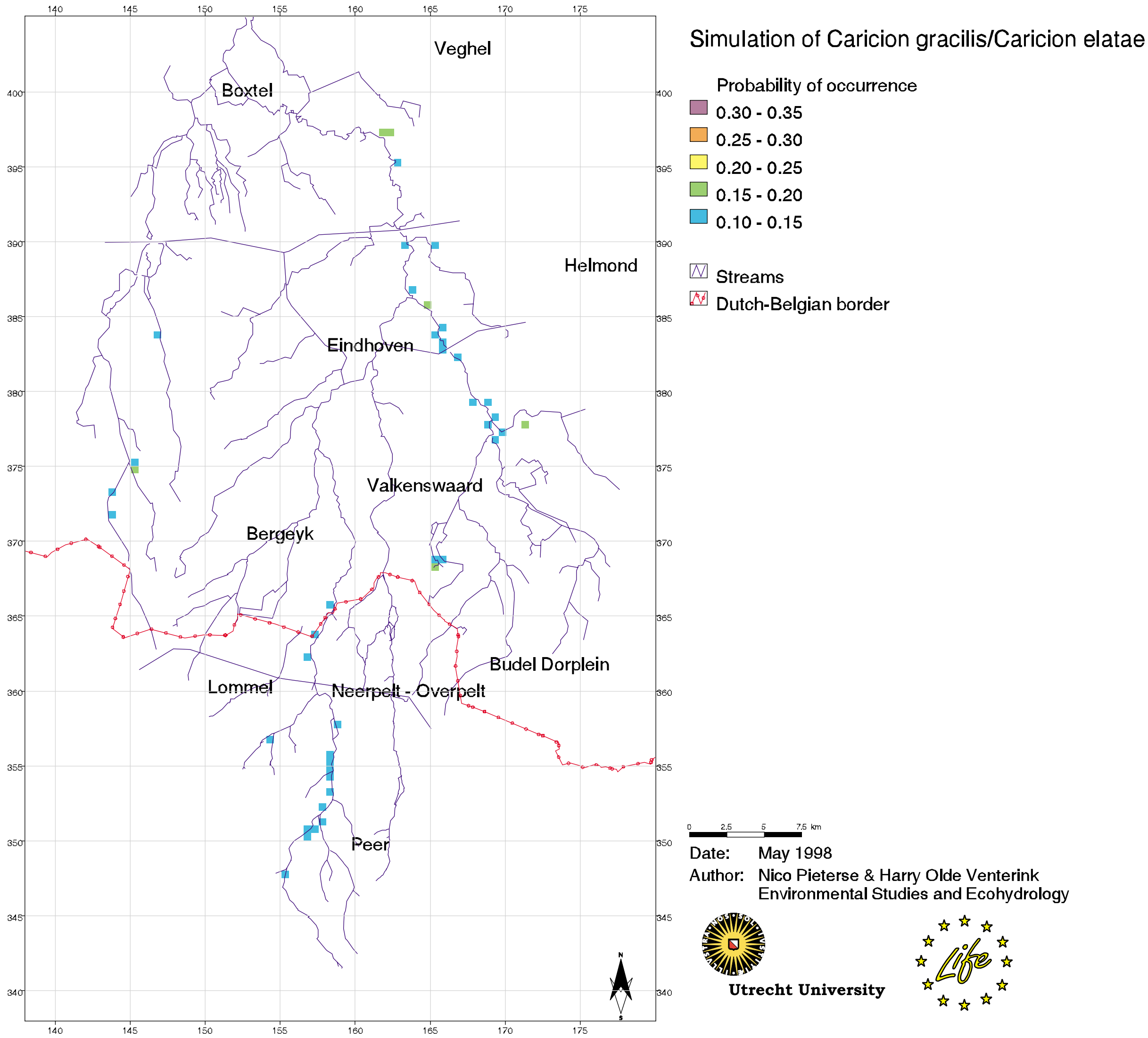


Figure 14 Map with the probability of occurrence of the vegetation type ***Caricion nigrae*** *in the Dommel catchment.*



Date: May 1998
Author: Nico Pieterse & Harry Olde Venterink
Environmental Studies and Ecohydrology

*Figure 15 Map with the probability of occurrence of the vegetation type **Caricion gracilis/ Caricion elatea** in the Dommel catchment.*

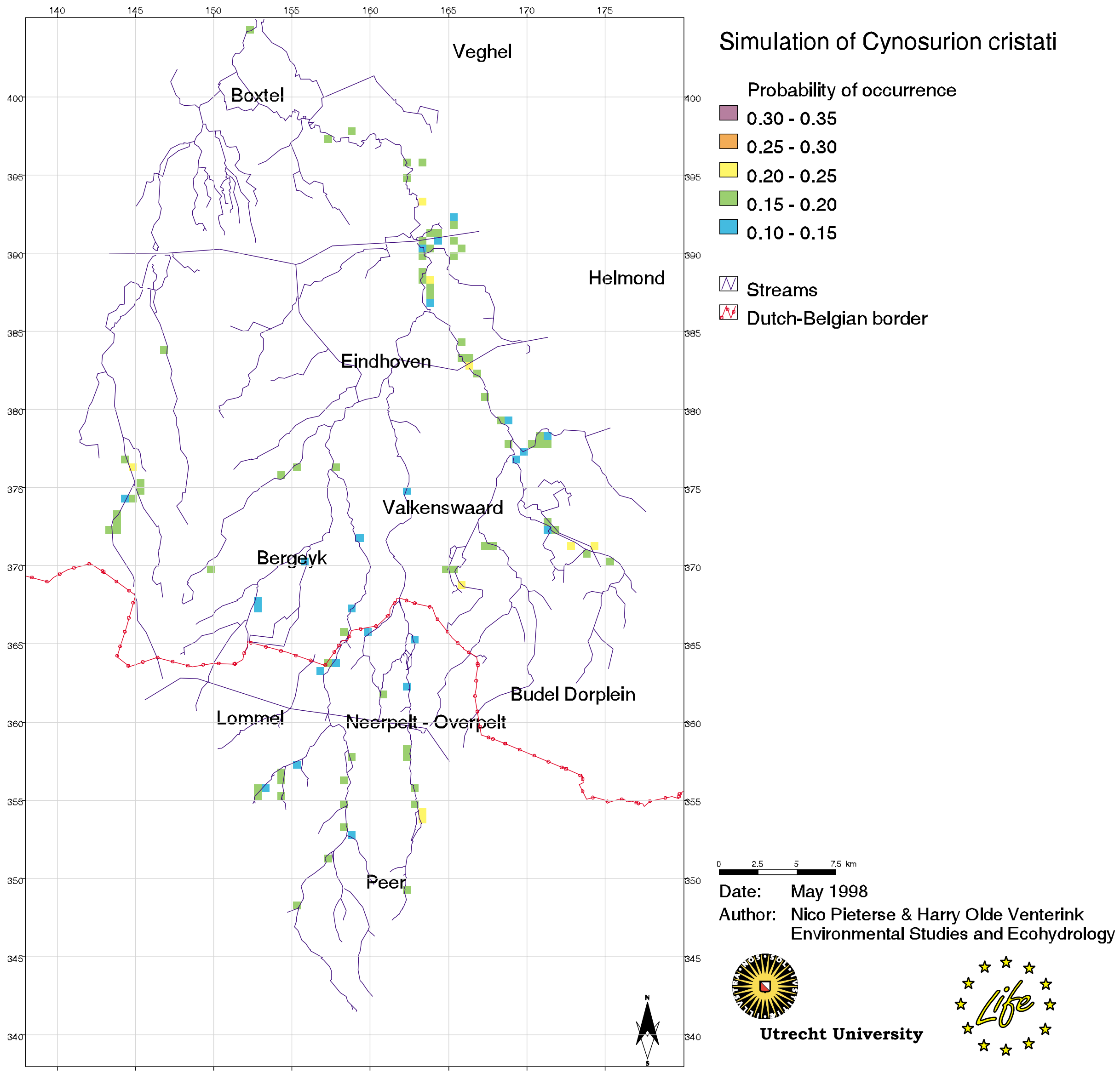


Figure 16 Map with the probability of occurrence of the vegetation type ***Cynosurion cristati*** *in the Dommel catchment.*

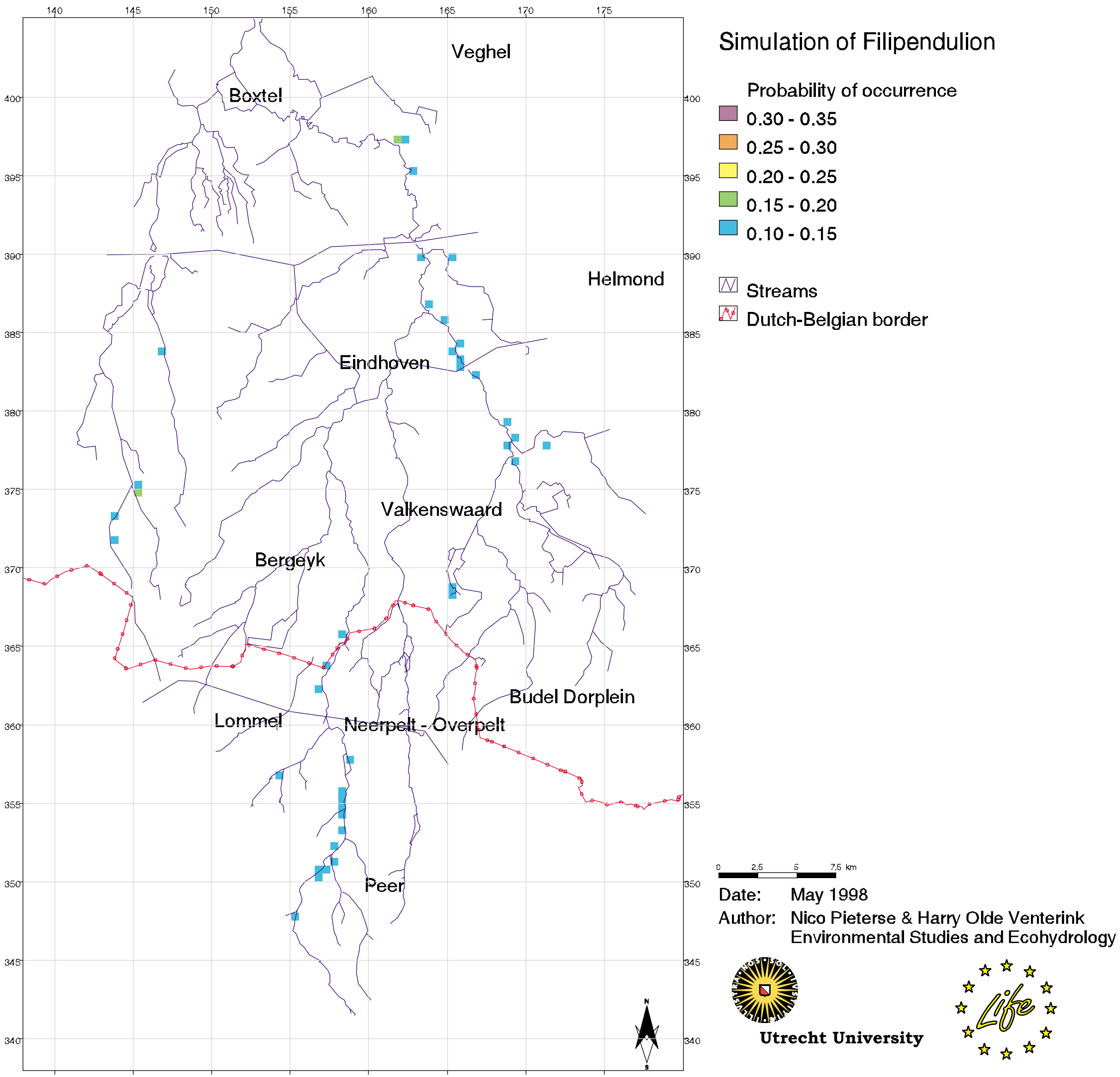


*Figure 17 Map with the probability of occurrence of the vegetation type **Filipendulion** in the Dommel catchment.*

5. Conclusions and Discussion

In the nature planner, calculations for environmental evaluations and RIVM scenario's are performed with grid cells of 250 x 250 meters wide (Kros, in prep) aggregated to 5km x 5km cells. For small river catchments, higher detail is preferable because river valleys can be as small as 100 meters. Because the input routine of SMART2 is rewritten for application within the GIS ArcInfo and MOVE is completely rewritten in the ArcInfo environment, calculations can now be performed on every level of detail. The combination SMART2 and MOVE is applied for the Dommel valleys with a resolution of 100 m. This scale level seems to be appropriate.

As a part of this study Ellenberg indication values for nutrient availability were calibrated with measured habitat variables. To find an environmental variable that correlates with the Ellenberg indication values for nutrient availability, a comprehensive field experiment in the catchment areas of the Dommel and the Zwarte Beek was carried out. The results of this study indicate that Ellenberg N-values are calibrated most appropriately with a combination of the available amounts of N, P (and K). Because P and K availability can not be predicted by SMART2, it is not possible to include these nutrients in the model-simulations. In stead, the observed significant relationship between N-mineralization and Ellenberg N-values is used to link SMART and MOVE for nutrient availability.

To simulate the acidity of peat soils by SMART2, it was necessary to include capillary rise of groundwater to the root zone, otherwise the acidity would be simulated much too low. In addition, acidity simulations of sandy soils with spring groundwater levels above 15 cm, are considered to be unrealistic. Therefore sandy soils with spring groundwater levels above 15 cm get the maximal spring water level of 15 cm below surface.

SMART2 simulations are compared with measurements in the Dommel catchment. Simulations of acidity are comparable with measured acidity. N-mineralization simulations do not match with field observations. Moreover, these simulations do not differentiate between various sites, although these sites have different soil properties and different hydrological regimes. The MOVE variable Ellenberg-N is therefore excluded from the MOVE equations. Because the multiple regression equations of MOVE cannot be altered, the optimum N for each plant species is used instead.

MOVE simulations were carried out for the catchment area of the river Dommel. Simulations are in agreement with expectations of potentials for nature development, based upon fieldwork. The simulations show that in the larger part of the catchment, the probability of occurrence of species-rich grasslands and fens are very low. At some locations however, relatively high probability of occurrence for especially *Calthion palustris* and *Junco-Molinion* are simulated. Because habitat conditions in the Dommel catchment are more likely to be eutrophic than oligothropic, the probability of occurrence of oligothrophic and mesothrophic vegetation types (*Junco-Molinion, Caricion nigrae and Calthion palustris*) will lower than simulated. From inventories of the occurrence of grasslands and fens in this catchment, it is concluded that hardly any of these vegetation types, and especially the species-rich types, are left. Therefore a validation of model simulations is not carried out.

Acknowledgements

We would like to thank Jaap Wiertz, Rob Alkemade and Michel Bakkenes (RIVM) for providing the Nature Planner and MOVE. Hans Kros (DLO-SC) is thanked for providing SMART2 and additional information. In addition we wish to thank Geert de Blust and Christian Dubois (Institute of Nature Conservation, Flanders) for providing the maps of the vegetation inventory of the Belgian part of the Dommel catchment, and Jaap van der Linden (province of N-Brabant, The Netherlands) for providing these maps of the Dutch part of the catchment. Sander Borghuis is thanked for digitizing a large part of the vegetation maps of the Dutch part of the Dommel catchment. Officials of the State Nature Conservancy, Nature Monuments, the city of Eindhoven, the Zwarte Beek nature reserve and military authorities are thanked for the permission to carry out field experiments in their nature reserves.

References

Aggenbach, C., Kolkman, S., Vegter, U. & Bokeloh, D. (1990). Hydro-ecologie van de Zwarte Beek vallei, een mesotroof veen in de Belgische Kempen. Rijksuniversiteit Groningen, Groningen.

Alkemade, J. R. M., Wiertz, J. & Latour, J. B. (1996). Kalibratie van Ellenbergs Milieu-Indicatiegetallen aan Werkelijk Gemeten Bodemfactoren. RIVM, Bilthoven.

Baeyens, L. (1976). Bodemkaart van Belgie 1:20000. I.W.O.N.L.

Berendse, F., Oomes, M. J. M., Altena, H. J. & De Visser, W. (1994). A comparative study of nitrogen flows in two similar meadows affected by different groundwater levels. *Journal of Applied Ecology* **31,** 40-48.

Bio, A. M. F., Alkemade, R. & Barendregt, A. (1998). Determining alternative models for vegetation response analysis: a non-parametric approach. *Journal of Vegetation Science* **9,** 5-16.

de Blust, G., Froment, A., Kuyken, E., Nef, L. & Verheyen, R. (1985). *Biologische Waarderingskaart van België. Algemene Verklarende Tekst*. J. Huylebroeck, Brugge.

de Vries, F. & Denneboom, J. (1992). De bodemkaart van Nederland digitaal: technisch document 1. SC-DLO, Wageningen.

Ellenberg, H., Weber, H. E., Düll, R., Wirth, V., Werner, W. & Paulißen, D. (1991). Zeigerwerte von Pflanzen in Mitteleuropa. *Scripta Geobotanica* **18,** 1-248.

Ertsen, A. C. D., Alkemade, J. R. M. & Wassen, M. J. (1998). Calibrating Ellenberg indicator values for moisture, acidity, nutrient availability and salinity in the Netherlands. *Plant Ecology* **135,** 113-124.

Jongman, R. H. G., ter Braak, C. J. F. & van Tongeren, O. F. R. (1995). *Data Analysis in Community and Landscape Analysis*, 2nd edition. Cambridge University Press, Cambridge.

Kros, J. (in prep). Verbetering, verfijning en toepassing van SMART2 ten behoeve van de Milieubalans, Milieuverkenning en Natuurverkenning. RIVM.

Kros, J., Reinds, J., de Vries, W., Latour, J. B. & Bollen, M. J. S. (1995). Modelling of soil acidity and nitrogen availability in natural ecosystems in response to changes in acid deposition and hydrology. SC-DLO & RIVM, Wageningen.

Latour, J. B. & Reiling, R. (1993). A multiple stress model for vegetation ("MOVE"); a tool for scenario studies and standard setting. *The Sience of the Total Environment* **Suppl,** 1513-1526.

Latour, J. B., Reiling, R. & Wiertz, J. (1993). MOVE: a multiple stress model for vegetation. In *The use of hydro-ecological models in the Netherlands*, vol. 47 (ed. J. C. Hooghart and C. W. S. Posthumus), pp. 53-66. TNO Committee on Hydrological Research, Ede, The Netherlands.

Latour, J. B., Staritsky, I. G., Alkemade, J. R. M. & Wiertz, J. (1997). De Natuurplanner. Decision Support Systeem natuur en milieu, versie 1.1. RIVM, Bilthoven.

Loopstra, I. L. & Maarel, E. V. d. Toetsing van de Ecologische Soortengroepen in de Nederlandse Flora aan het Systeem van Indicatiewaarden volgens Ellenberg. Rijksinstituut voor Onderzoek in de Bos- en Landschapsbouw 'De Dorschkamp'. Rapport nr. 381, Wageningen.

Olde Venterink, H. & Wassen, M. J. (1997). A comparison of six models predicting vegetation response to hydrological habitat change. *Ecological Modelling* **101,** 347-361.

Olde Venterink, H., Pieterse, N. M., Wassen, M. J. & Verkroost, A. W. M. (1998). Demonstration Project for the Development of Integral Management Plans for Catchment Areas of Small Trans-Border Lowland Rivers: the River Dommel. 4. Alnion, an Ecohydrological Response Model for Wet and Moist Woodlands in Brook Valleys. Research Group Environmental Studies and Ecohydrology, Utrecht University.

Olff, H. (1992). Deelprogramma Natuurontwikkeling; een Verkenning van Modellen. IBN-DLO, Wageningen.

Olff, H., Berendse, F. & de Visser, W. (1994). Changes in nitrogen mineralization, tissue nutrient concentrations and biomass compartmentation after cessation of fertilizer application. *Journal of Ecology* **82,** 611-620.

Pedroli, B. (1989). The Nature of Landscape. PhD thesis, University of Amsterdam.

Pedroli, G. B. M. & Borger, G. J. (1990). Historical land use and hydrology, a case study from eastern Noord-Brabant. *Landscape Ecology* **4,** 237-248.

Pieterse, N. M., Olde Venterink, H., Schot, P. P. & Verkroost, A. W. M. (1998a). Demonstration Project for the Development of Integral Management Plans for Catchment Areas of Small Trans-Border Lowland Rivers: the River Dommel. 1. Streamflow, a GIS-based Environmental Assessment Tool for Lowland Streams. Research Group Environmental Studies and Ecohydrology, Utrecht University, Utrecht.

Pieterse, N. M., Schot, P. P. & Verkroost, A. W. M. (1998b). Demonstration Project for the Development of Integral Management Plans for Catchment Areas of Small Trans-Border Lowland Rivers: the River Dommel. 2. Simulation of the Regional Hydrology of the Dommel Catchment (in Dutch, with English Summary). Research Group Environmental Studies and Ecohydrology, Utrecht University, Utrecht.

Raison, R. J., Connell, M. J. & Khanna, P. K. (1987). Methodoly for studying fluxes of soil mineral-N *in situ*. *Soil Biology and Biochemistry* **19,** 521-530.

Runhaar, J. (1989). Toetsing van het Ecotopensysteem II: Rapportage van het Veldwerk. CML, Leiden.

Steur, G. G. L. & Heijink, W. (1991). Bodemkaart van Nederland schaal 1:50000, algemene begrippen en indelingen. SC-DLO, Wageningen.

Stuurman, R. J. & Pakes, U. (1991). Hydrologische systeemanalyse Noord- en Midden Limburg. Toepassing bij onderzoek naar de bepaling van kansrijkdom van kwelgebieden. TNOgg.

Stuurman, R. J., van der Meij, J. L., Bierheuvel, A. & Pakes, U. (1990). De grondwaterstromingsstelsels en de grondwatersamenstelling van de provincie Noord-Brabant. TNOgg, Delft.

Stuurman, R. J. & van der Weg, H. (1993). De hydrologie van de Urkhovense Zeggen bij Eindhoven. TNO.

ter Braak, C. J. F. & Gremmen, N. J. M. (1987). Ecological amplitudes of plant species and the internal consistency of Ellenberg's indicator values for moisture. *Vegetatio* **69,** 79-87.

ter Braak, C. J. F. & Looman, C. W. N. (1986). Weighted averaging, logistic regression and the Gaussian response model. *Vegetatio* **65**.

Thunnissen, H. R., Olthof, P., Geltz, P. & Veltz, L. (1992). Grondgebruiksdatabank van Nederland vervaardigd met behulp van Landsat Thematic Mapper opnamen. DLO-staring centrum, Wageningen.

van Leeuwen, C. G. (1966). A relation theoretical approach to pattern and process in vegetation. *Wentia* **15,** 25-46.

van Wirdum, G. (1991). Vegetation and hydrology of floating rich-fens. Ph.D thesis, University of Amsterdam.

Wassen, M. J. & Schot, P. P. (1992). Hydro-ecologische modellen. *Landschap* **9,** 83-105.

Wiertz, J., van Dijk, J. & Latour, J. B. (1992). MOVE: Vegetatie-module; de Kans op Voorkomen van ca. 700 Plantensoorten als Functie van Vocht, pH, Nutrienten en Zout. RIVM, Bilthoven.

APPENDICES

Appendix 1. Translation of Belgian soil types (1:10.000 soil map codes) to SMART2 soil classes

Sand			**Clay**		**Löss**	**Peat**
Non Calcareous		**Calcarous**	**Non Calcareous**	**Calcarous**		
SP	**SR**	**SC** [1]	**CN** [2]	**CC** [2]	**LN** [2]	**PN**
OB	P ..					V
OE	tP ..					vP ..
ON	tS ..					vS ..
OT	S ..					vZ ..
tX	wS ..					Z ..(v)
tZ ..	sL ..					S ..(v)
wZ ..	tL ..					P ..(v)
X						
Z ..						

Belgian soil codes are after Baeyens (1976). SMART2 soil codes are accoring to Kros et al. (1995). [1]*This information could not be extraxted from the soil classification.* [2] *Not present in the Belgian part of the research area.*

Appendix 2: Translation of observed vegetation codes to SMART2 vegetation classes

PIN	SPR	DEC	HEA	GRP
Pp ..	Pa ..	Fs ..	Cd ..	Ha ..
	Pi ..	Lh ..	Ce ..	Hc ..
	Pm ..	Ls ..	Cg ..	Hf ..
		Mm	Cm ..	Hj ..
		Mr	Cp ..	Hm ..
		N ..		Hn ..
		Qa ..		Ho ..
		Qb ..		Hp ..
		Qs ..		Hr ..
		Se ..		Hu ..
		Sf ..		Hz ..
		Sg ..		Mc ..
		Sm ..		Mr ..
		So ..		Ms ..
		Sz ..		
		Va ..		
		Vc ..		
		Vm ..		
		Vn ..		
		Vo ..		
		Vt ..		

Translation of observed Belgian vegetation codes to SMART2 vegetation classes. The Belgian vegetation codes are derived from the national inventarisation and evaluation of the vegetation of Belgium (de Blust et al., 1985). SMART2 vegetation codes are according to Kros et al. (1995). PIN = Pine forest, SPR = Spruce forest, DEC = deciduous forest, HEA = heather, GRP = nutrient poor grassland.

PIN	SPR	DEC	HEA	GRP
1100	1109	900	300	200
1102		901	301	201
1103		902	302	202
1104		903	303	203
1107		904	305	204
1112		905	306	206
		906	308	207
		907	309	208
		908	310	209
		909	311	211
		916	312	213
		1000	313	214
		1001	314	215
		1002	315	216
		1003	316	217
		1004	318	218
		1005	319	221
		1009	320	307
		9006	321	507
			326	508
				509
				600
				601
				602
				603
				604
				605
				606
				607
				608
				609
				610
				611
				612
				613
				614

Translation of observed provincial vegetation codes to SMART2 vegetation codes. Provincial vegetation codes are according to Anonymous (1991). SMART2 vegetation classes are according to Kros et al. (1995). PIN = Pine forest, SPR = Spruce forest, DEC = deciduous forest, HEA = heather, GRP = nutrient poor grassland.

Appendix 3: List of characteristic species of plant communities.

Names of Plant communities and characteristic species are based upon Schaminée et al. (1995; 1996), except Filipendulion is based upon den Held (1991).

CBS	***Nardo-Galion saxatilis***
93	*Arnica montana*
251	*Carex pilulifera*
568	*Gentiana pneumonanthe*
857	*Nardus stricta*
924	*Pedicularis sylvatica*
950	*Platanthera bifolia*
962	*Polygala serpyllifolia*
1008	*Potentilla erecta*
1199	*Danthonia decumbens*
1258	*Succisa pratensis*

CBS	***Junco-Molinion***
236	*Carex hostiana*
248	*Carex panicea*
255	*Carex pulicaris*
261	*Carex oederi subsp. oederi*
332	*Cirsium dissectum*
461	*Epipactis palustris*
556	*Galium uliginosum*
568	*Gentiana pneumonanthe*
679	*Juncus conglomeratus*
921	*Parnassia palustris*
1258	*Succisa pratensis*
1332	*Valeriana dioica*
1544	*Agrostis canina*
1616	*Dactylorhiza maculata*
1933	*Luzula multiflora*

CBS	***Calthion palustris***
60	*Angelica sylvestris*
225	*Carex disticha*
335	*Cirsium palustre*
373	*Crepis paludosa*
466	*Equisetum palustre*
526	*Filipendula ulmaria*
556	*Galium uliginosum*
670	*Juncus acutiflorus*
679	*Juncus conglomeratus*
763	*Lotus uliginosus*
772	*Lychnis flos-cuculi*
1160	*Scirpus sylvaticus*
2338	*Caltha palustris*

CBS	***Alopecurion pratensis***
42	*Alopecurus pratensis*
519	*Festuca pratensis*
532	*Fritillaria meleagris*
715	*Lathyrus pratensis*
725	*Leontodon autumnalis*
1043	*Ranunculus auricomus*
1093	*Rumex acetosa*
1306	*Trifolium repens*
1369	*Vicia cracca*

CBS	***Arrhenatherion elatioris***
35	*Allium vineale*
96	*Arrhenatherum elatius*
135	*Bellis perennis*
161	*Bromus hordeaceus subsp. hordeaceus*
371	*Crepis biennis*
394	*Daucus carota*
485	*Eryngium campestre*
550	*Galium mollugo*
692	*Knautia arvensis*
922	*Pastinaca sativa*
928	*Peucedanum carvifolia*
940	*Pimpinella major*
1185	*Senecio erucifolius*
1299	*Trifolium dubium*
1312	*Trisetum flavescens*
1351	*Veronica chamaedrys*
1369	*Vicia cracca*
1954	*Tragopogon pratensis*
2385	*Phleum pratense*

CBS	***Cynosurion cristati***
42	*Alopecurus pratensis*
135	*Bellis perennis*
235	*Carex hirta*
296	*Cerastium fontanum subsp. vulgare*
386	*Cynosurus cristatus*
519	*Festuca pratensis*
725	*Leontodon autumnalis*
756	*Lolium perenne*
1299	*Trifolium dubium*
1305	*Trifolium pratense*
2385	*Phleum pratense*
6517	*Taraxacum officinale*

CBS	***Lolio-Potentillion anserinae***
18	*Agrostis stolonifera*
40	*Alopecurus geniculatus*
235	*Carex hirta*
245	*Carex cuprina*
959	*Poa trivialis*
1010	*Potentilla reptans*
1056	*Ranunculus repens*
1057	*Ranunculus sardous*
1098	*Rumex crispus*
1300	*Trifolium fragiferum*

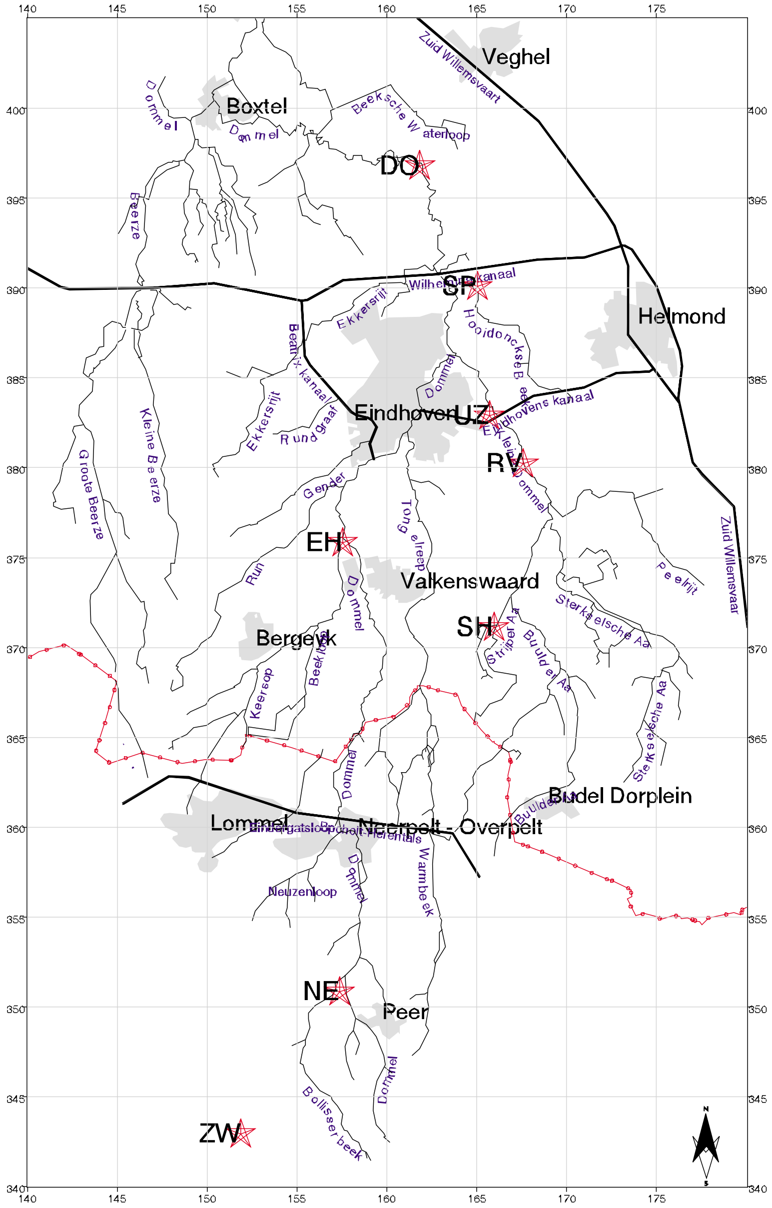
CBS	***Caricion nigrae***
219	*Carex curta*
228	*Carex echinata*
346	*Potentilla palustris*
420	*Dryopteris cristata*
456	*Epilobium palustre*
1048	*Ranunculus flammula*
1362	*Veronica scutellata*
1385	*Viola palustris*

CBS	***Caricion gracilis/elatae***
173	*Calamagrostis canescens*
211	*Carex acuta*
237	*Carex elata*
249	*Carex paniculata*
254	*Carex pseudocyperus*
259	*Carex riparia*
267	*Carex vesicaria*
427	*Thelypteris palustris*
490	*Eupatorium cannabinum*
665	*Iris pseudacorus*
783	*Lysimachia thyrsiflora*
784	*Lysimachia vulgaris*
813	*Mentha aquatica*
929	*Peucedanum palustre*
1099	*Rumex hydrolapathum*
2376	*Galium palustre*

CBS	***Filipendulion***
211	*Carex acuta*
212	*Carex acutiformis*
259	*Carex riparia*
457	*Epilobium parviflorum*
490	*Eupatorium cannabinum*
496	*Euphorbia palustris*
526	*Filipendula vulgaris*
651	*Hypericum quadrangulum*
665	*Iris pseudacorus*
784	*Lysimachia vulgaris*
1245	*Stachys palustris*
1333	*Valeriana officinalis*
2376	*Galium palustre*

CBS	***Phragmitetea***
28	*Alisma plantago-aquatica*
326	*Cicuta virosa*
463	*Equisetum fluviatile*
780	*Lycopus europaeus*
844	*Myosotis palustris*
1099	*Rumex hydrolapathum*
1155	*Scirpus lacustris subsp. lacustris*
1215	*Berula erecta*
1216	*Sium latifolium*
1229	*Sparganium erectum*
1317	*Typha angustifolia*

Appendix 4: Major streams in the Dommel catchment, and fieldwork locations.



▨ Dutch-Belgian border
▨ Major urban areas
▨ Streams
▨ canals
★ Fieldwork locations
DO = Dommelbeemden
UZ = Urkhovense zeggen
SP = Het Spekt
RV = Rietvelden
SH = Strijper Heg
EH = Elshouters
NE = Dommeldal near Neerhoksent
ZW = Zwarte Beek

0 2.5 5 7.5 km

Date:	May 1998
Author:	Nico Pieterse Environmental Studies and Ecohydrology

Utrecht University

Reports in the EU-LIFE Dommel series

Verkroost, A.W.M., Olde Venterink, H., Pieterse, N.M., Schot, P.P. and Wassen, M.J., 1998. Demonstration Project for the Development of Integrated Management Plans for Catchment Areas of Small Trans-Border Lowland Rivers: the River Dommel. **1**. Ecohydrological Modeling and Integrated management Planning in the Catchment of the River Dommel, Department of Environmental Science, Utrecht University.

Pieterse, N.M., Olde Venterink, H., Schot, P.P. and Verkroost, A.W.M., 1998. Demonstration Project for the Development of Integrated Management Plans for Catchment Areas of Small Trans-Border Lowland Rivers: the River Dommel. **2**. Streamflow, a GIS-based Environmental Assessment Tool for Lowland Rivers, Department of Environmental Science, Utrecht University.

Pieterse, N.M., Schot, P.P. and Verkroost, A.W.M., 1998. Demonstration Project for the Development of Integrated Management Plans for Catchment Areas of Small Trans-Border Lowland Rivers: the River Dommel. **3**. Simulation of the Regional Hydrology of the Dommel Catchment (in Dutch, with English Summary)., Department of Environmental Science, Utrecht University.

Pieterse, N.M., Olde Venterink, H., Schot, P.P., Wassen, M.J. and Verkroost, A.W.M., 1998. Demonstration Project for the Development of Integrated Management Plans for Catchment Areas of Small Trans-Border Lowland Rivers: the River Dommel. **4**. Habitat and Vegetation Response Prediction for Meadows and Fens, Application of SMART-MOVE on a Regional Scale., Department of Environmental Science, Utrecht University.

Olde Venterink, H., Pieterse, N.M., Wassen, M.J. and Verkroost, A.W.M., 1998. Demonstration Project for the Development of Integrated Management Plans for Catchment Areas of Small Trans-Border Lowland Rivers: the River Dommel. **5**. Alnion, an Ecohydrological Response Model for Wet and Moist Woodlands in Brook Valleys., Department of Environmental Science, Utrecht University.

Olde Venterink, H., Pieterse, N.M., Wassen, M.J. and Verkroost, A.W.M., 1998. Demonstration Project for the Development of Integrated Management Plans for Catchment Areas of Small Trans-Border Lowland Rivers: the River Dommel. **6**. Ecostream, A Response Model for Aquatic Ecosystems in Lowland Streams., Department of Environmental Science, Utrecht University.

Kwakernaak, C., Van der Windt, N., Van der Gaast, J., Van Os, J. and Pieterse, N.M., 1998. Demonstration Project for the Development of Integrated Management Plans for Catchment Areas of Small Trans-Border Lowland Rivers: the River Dommel. **7**. Naar een Ecologisch Herstel van het Dommeldal; Scenario's voor het EU-project LIFE-Dommel (in Dutch)., Winand Staring Centrum for Integrated Land, Soil and Water Research (SC-DLO), Wageningen.

De Jong, D.M., 1998. Demonstration Project for the Development of Integrated Management Plans for Catchment Areas of Small Trans-Border Lowland Rivers: the River Dommel. **8**. De beleidscontext van grensoverschrijdende samenwerking voor de Dommel, een beschrijving van het vigerend beleid in Vlaanderen (in Dutch)., Leerstoelgroep Milieu en Beleid, Katholieke Universiteit Nijmegen, Nijmegen.