

# Technical Documentation for SUMO2 v. 3.2.1

G.W.W. Wamelink

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Wettelijke Onderzoekstaken Natuur & Milieu



WAGENINGENUR

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# **Technical Documentation for SUMO2 v. 3.2.1**

G.W.W. Wamelink

**Werkdocument 108**

Wettelijke Onderzoekstaken Natuur & Milieu

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## Summary

In This document the model SUMO2 v. 3.2.1 is described. It contains technical information about all subroutines, input, output and a general description of the model. This document is a part of the A-quality status of SUMO2.

### Meta information of SUMO2 v3.2.1

Name : SUMO2  
Version: : 3.2.1  
Release date : 17-11-2004  
Executable : part of SMART2; called from SMART2 via interface sms\_nl\_nt.exe  
Platform : Dos, Windows  
Costs : free of charge  
Contact : Wieger Wamelink (wieger.wamelink@wur.nl)  
Support : None, unless agreed otherwise  
Output : ascii-files  
Time step : one year  
Resolution : free (SUMO2 is a point model)  
Model type : Process model  
Disclaimer : Alterra is not responsible nor are the model makers for any (financial) damage that the model may cause in any way.

### SUMO2

SUMO2 simulates the vegetation succession and biomass increment for several vegetation types on the basis of five competing functional types (grasses and herbs, dwarf shrubs, shrubs and two tree species) and three organs (roots, wood, leaves). The functional types compete for light, nitrogen and phosphorus. The biomass increment is influenced depended on the functional type by moisture availability temperature and management including grazing. The model uses information from SMART2 and from site specific vegetation and management maps.

### Necessary input

SUMO2 needs several parameter files as input, they are provided with the model and may not be changed.

SUMO2 also needs site specific information which may be provided by the user. Two input files are obligatory, vegout.txt and extra-manag.txt. Both files are described in the user documentation. Information has to be provided on a grid basis, however the size of the grid is free to choose, since SUMO and SMART2 are point models.

### Output

The user can not select the desired output. The SUMO2 version delivered by the makers will produce the requested output by the user. The different output files are described in the user documentation. Common output may contain biomass (total and per functional type and organ), N-content and P-content of biomass and litter, litter biomass, vegetation height and N/P ratios.

**SMART2**

SUMO2 can not, without major adjustments, be run as an independent model. The model SMART2 is necessary for proper model runs and will be provided as well.

**Application area**

SUMO2 may be used in The Netherlands and the UK for terrestrial ecosystems (grassland, heathland and forest). The model was also tested for applications for Europe except the southern dry parts of Spain, Italy and Greece for forest ecosystems. It will probably function for similar areas in Western Europe, but this has not been tested. Deposition and climatologically scenarios as well as management scenarios have been tested. In principle SUMO was developed for natural areas, however manuring up to 200kg/ha N is possible (and tested).



# 1 Introduction

The model SUMO (short for succession model) was developed as an extension of the model SMART2. In SMART2 the vegetation development and litter fall was modelled in the simplest way possible, influences of management and succession were neglected. The first version of SUMO was able to model the effects of vegetation succession and management on the vegetation and was integrated in the model SMART2. In later versions of SUMO the management was extended (forest version of SUMO), the effect of grazing added (SUMO2), the phosphorus cycle added (SUMO2 phosphorus version) and for the UK the effect of Temperature, nitrogen fixation by legumes and changes in management were added (SUMO2 version 3.1). The first SUMO2 version that was build and described under the quality roles was SUMO2 v3.0. This document v. 3.2.1 is an adjusted version and includes the modelling of magnesium, potassium and calcium cycles and the effect of CO<sub>2</sub> concentration on the growth. Furthermore, the temperature and moisture modelling were adjusted. Meta information about SUMO2 can be found in [meta\\_information.doc](#).

## 1.1 Goal

SUMO was developed as an extension of the model SMART2, to provide SMART2 with feed back about the yearly litter production and nitrogen content of the litter. SUMO does so by modelling several different vegetation types and five functional types. The model is able to simulate succession and the effects of nature management and grazing. The basis of the model was the nitrogen cycling in the vegetation to which the phosphorus cycling was added in 2001. In 2005 calcium, potassium and magnesium cycling were added to SUMO2 and the simulation of the effect of water availability on the vegetation growth was changed. In 2006 the effects of CO<sub>2</sub>, temperature on the growth were incorporated.

## 1.2 Boundaries

The model SUMO was tested for The Netherlands and for the UK. The model was applied for the modelling of European forest to evaluate the effects of climate change on forest growth. The model was used for all European foreststypes except those occurring in the south of Spain, Italy and Greece, although the common tree species for the south of Europe were added and tested. The model only simulates vegetation development for the terrestrial vegetation types grassland, heathland and forest for five functional types (grasses and herbs, dwarfshrubs, shrubs and two tree species). The model is tested for using several deposition and management scenarios. The limits for the input variables for SUMO can be found in [limits.doc](#).

## 1.3 Bugs

This chapter describes known bugs and how to deal with them.  
At the moment no bugs are known (09-07-2008)

SUMO2 may produce error messages, which are channelled through SMART2. The most frequent occurring one is that the coordinates of the grids are not the same for the three input

files containing grid information (grid\_s\_v.dat (SMART2) and vegout.txt and extra\_manag.txt). The coordinates of the files then have to be adjusted.

When SUMO2 crashes this almost always happens in the (licht.for) light subroutine. However, the problem can be present anywhere in the program or in the inputfiles, a thorough check is then almost always needed (preferably by the model makers).

SUMO2 does not check whether or not the input is within the ranges provided in this document!

## 1.4 Model concepts

The SUMO2 model version 3.2.1 is the result of many years of programming testing and validating. The model concepts are written down in many reports and articles of which the main are: Wamelink *et al.* (2000a), Wamelink (2007) and de Vries *et al.* (2007). Many assumptions and model simplifications have been made. Some of them are given here below, but this has to be extended.

In principle SUMO only simulates vegetation processes. Soil processes (SMART2) and processes in the air are not included in the model. Grazing is included in the model, but only as a way (of management) to remove nutrients from the system. SUMO is not a population dynamic model, therefore it is not possible to conclude anything about population sizes of grazers, besides the amount of grazers that can be maintained by the vegetation, and even then only with great care. The basis of SUMO is five functional types. SUMO does not model plant species, mainly because of lack of information about individual species and because the computer time necessary to simulate all species of the Dutch flora. Sumo has to be able to run on a (dutch) national scale, which also brings limitations. Normally, the smallest grid size is 250\*250m, although SUMO is, together with SMART2, in principle a point model. The model does not simulate the whole grid, but a representative point in the grid (given the input). The model is always validated on the point scale. Many processes in SUMO are neglected or simplified. The most important one is the light interception, which also differs from the rest of the concept used in SUMO. The light interception per vegetation layer is simulated as a fraction of the total availability (which is set to 1). In principle all other simulated processes (N, P, K, Mg, Ca uptake as well as effect of CO<sub>2</sub> concentration, moist availability and effect of temperature on the growth) are based on actual or simulated values. The growth per functional type is calculated both as a reduction function of the maximum growth, but also based on the Liebig principle of the most limiting element determining the growth. The Liebig principle is used to select the most limiting nutrient for the growth. This nutrient then is used together with the light availability, the moist availability, the carbon dioxide concentration and the temperature to reduce the maximum growth resulting in the realised growth. In SUMO the five functional types compete for nutrients and light. Temperature and carbon dioxide concentration influences the growth functional type (species specific for trees) the maximum growth.

## 2 Model description

In the first part all the subroutines in SUMO2 are described, including the formulas where the processes are based on. Hyperlinks give the opportunity to view all the parameters and variables used in the model. In the second part a tool is described to automatically transform the SUMO2 parameters into a database with parameters for the Natuurplanner. This tool was developed to improve the quality and accuracy of the making of the Natuurplanner database.

### 2.1 Subroutines in SUMO

This paragraph gives a short description of each subroutine in SUMO. Per subroutine a link towards an excel file is included which gives all parameters and variables used in the subroutine (with dimensions etc.). To follow the link press control and press the mouse button at the same time. The processes modelled in each subroutine are mentioned. Figure 2.1.1 gives the relation between the subroutines and functions in SUMO. The functions are described directly after the subroutine where it is called from. A translation of the code in the subroutines and functions into formulas can be found in Wamelink *et al.* (2008a) and Wamelink *et al.* (2008b). The relation between the input, output files and SUMO is given in fig. 2.1.2. The relation between the main subroutines and the steering program of SUMO2 (sumo\_dll.for) in running order is given in fig. 2.1.3

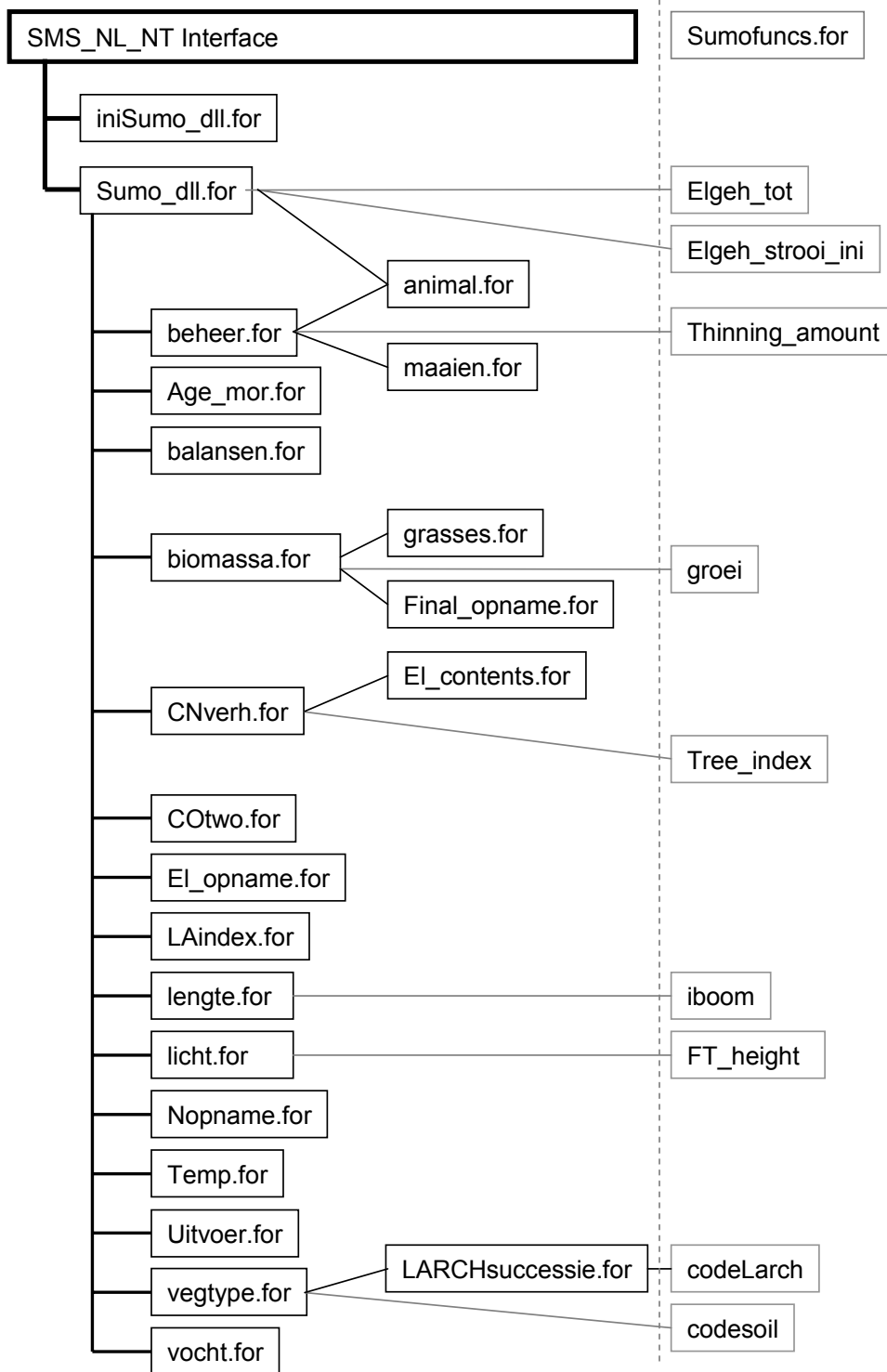


Figure 2.1.1 Relation between the subroutines and functions in SUMO v. 3.2.1. The subroutines *iniSUMO\_dll* and *SUMO\_dll* are called from the interface. Solid black lines indicate data exchange between subroutines, solid grey lines indicate data exchange between a subroutine and a function. Subroutines are indicated by dark rectangles, functions are indicated by grey rectangles. All functions are part of the file *sumofuncs.for*

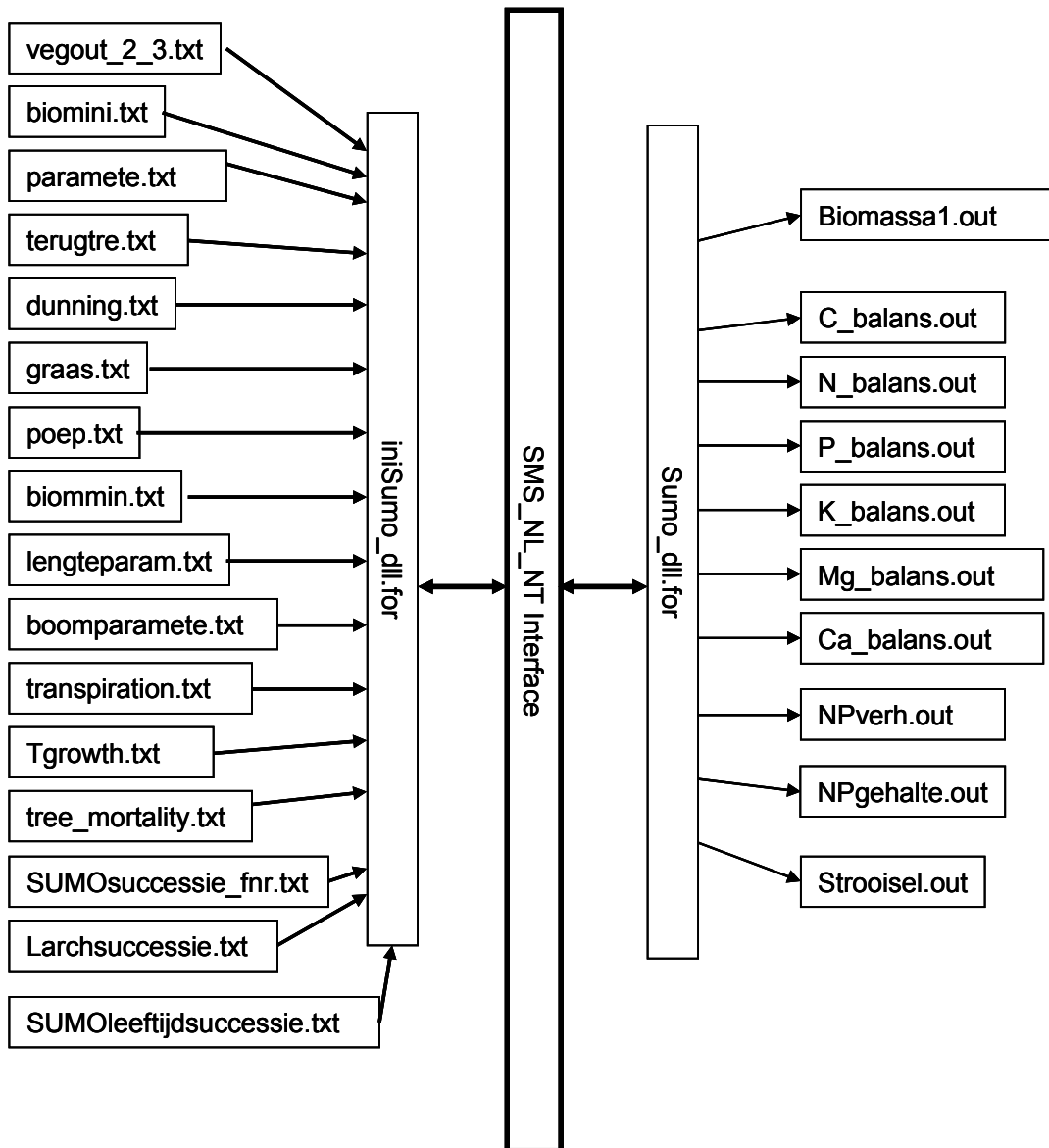


Figure 2.1.2. Relation between input and output files, the insialisation file (inisumo\_dll.for), the SMART2SUMO2 interface ( SMS\_NL\_NT Interface) and the main SUMO2 subroutine (sumo\_dll.for).

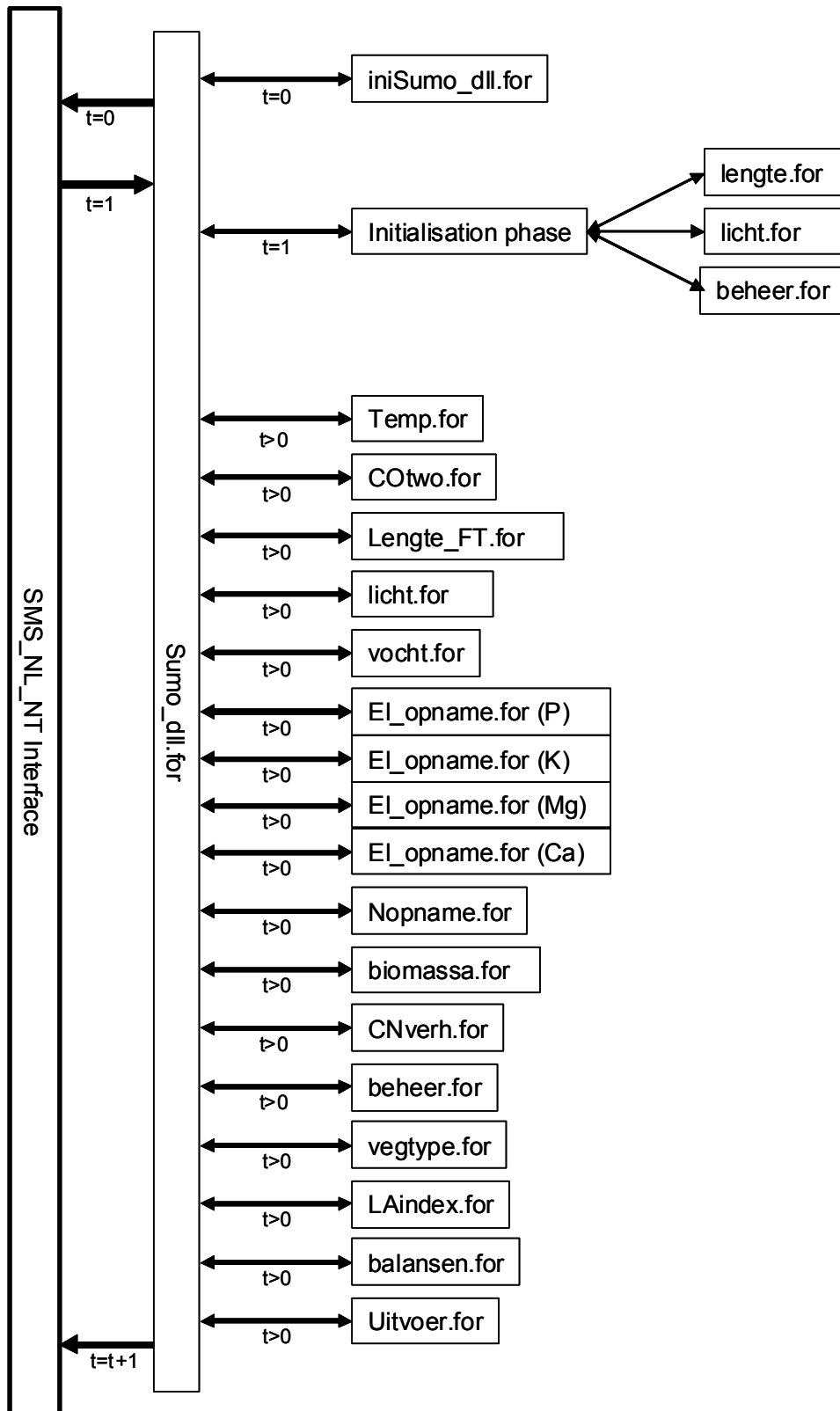


Figure 2.1.3. Relation between the SMART@SUMO2 interface and SUMO2 including the main subroutines and the time step. The subroutines are placed in running order.

### 2.1.1 The input file

Name of the file : inisumo.for  
First developed : 2000, for  $\beta$  version SUMO  
Changed : For all new versions of SUMO  
Background document : Wamelink *et al.* (2000), Wamelink *et al.*

This file is used for the reading of parameter values from input files. All parameters and values for them are described at the subroutines in which they are used. The input file is called from the SMART2SUMO2 interface (sms\_nl\_nt.for).

### 2.1.2 The SUMO dll

Name of the file : sumosm\_dll.for  
First developed : 2000, for  $\beta$  version SUMO  
Changed : For all new versions of SUMO  
Background document : Wamelink *et al.* (2000), Wamelink *et al.*

The SUMOsm\_dll is used for two purposes, first to initialise parameters and processes in the first year and second to serve as a communication program between the subroutines of SUMO and for the communication with SMART2. All the subroutines will be described in the next paragraphs. In this subroutine no processes are modelled. Originally it contained no subroutines, the subroutines were developed later containing the same or adjusted program lines as present in the original program. The relation between this subroutine and all other subroutines can be found in fig. 2.1.1.

Input parameters and variables for communication with SMART2 and iniSUMO. This also contains all parameters and variables that need to be stored for the next year run. (this file needs to be adjusted to the changes made for Forest Focus and the quality project).

Local parameters and variables for SUMOsm\_dll.for, including dimensions, technical ranges, origin in the case of parameters and the use in the several subroutines.

### 2.1.3 The function Elgeh\_tot

Name of the file : elgeh\_tot.for  
First developed : 2006, for the quality project  
Changed : -  
Background document : Wamelink *et al.* (2008)

This subroutine calculates the element content of N, P, K, Mg and Ca for the three organs roots, wood and leaves for living as well as dead organs.

### 2.1.4 The function Elgeh\_strooi\_ini

Name of the function : elgeh\_strooi\_ini  
First developed : 2006, for the quality project  
Changed : -  
Background document : Wamelink *et al.* (2008)

This function is only used in the initialisation phase of each grid. It calculates the element content (N, P, K, Mg and Ca) of litter.

### 2.1.5 Management subroutine

Name of the file : beheer.for  
First developed : 2000, for  $\beta$  version SUMO  
Changed : 2000, for the forest management version of SUMO; 2001, for the grazing version of SUMO; 2002, for the P version of SUMO; 2004, for SUMO 2.0; 2005, for SUMO 2.1, 2006 for the quality project  
Background document : Wamelink *et al.* (2000a), Wamelink *et al.* (2000b), Wamelink *et al.* (2001b), van Dijk *et al.* (2005), Smart *et al.* (in prep), Wamelink *et al.* (2008)  
Variables and parameters : [beheer.xls](#)

The grazing and mowing subroutines are activated from this subroutine.

Management implies the removal of biomass and therefore nitrogen from the system. In some cases management also influences the height of the functional types. In this subroutine three types of management are simulated: turf stripping (heathland), cutting (forests) and fire. The effect of grazing and mowing is modelled in two separate subroutines.

#### Turf stripping

After turf stripping the total biomass of the functional types is minimised to 0.002 ton•ha<sup>-1</sup> for dwarf shrubs and to 0.0002 ton•ha<sup>-1</sup> for the other functional types. Since after turf stripping the humus layer is also removed, SUMO signals SMART2 to remove the humus layer from the system. A milder form of heathland management is modelled as well; the removal of shrubs and trees. The biomass of shrubs and trees is then minimized.

#### Cutting

Cutting can influence all functional types. Three different types of forest management are modelled in SUMO. The first is extensive management. In this type of management, every 10 years 10% of the trees are harvested; this is implemented by reducing the biomass of all organs by 10%. The dead roots are transported to the dead roots-pool in SMART2 and mineralised. The rest of the cut biomass is removed from the system. The pool of reallocatable nitrogen is also reduced by 10%. The height of the trees is not influenced by cutting. The second management form is traditional (intensive) forest management with thinning every 5 years and clear-cut at the end of the management cycle. The amount of thinning depends on the tree species and the age of the stand (after Jansen *et al.* 1996). The cut biomass and a part of the reallocatable nitrogen are removed from the system, in the case of a clear-cut this is the total aboveground biomass and all the reallocated nitrogen. The biomass of the non-tree functional types is assumed to be destroyed for 90% and added to the litter. The forest is replanted after clear-cut; the height and age are set back to the height of planted young trees. The third management type is coppicing, which is simulated for a few tree species only: willow, ash, alder and oak. For willow, ash and alder the shoots are harvested every seven years, for oak every 30 years. For all tree species 80% of the above ground biomass is harvested. A large part of the functional type herbs is assumed to be destroyed (90%) and is added to the dead roots and litter pools, shrubs are assumed to be actively removed from the system. The height of the remaining stub after management is set to 0.3 m.



## Fire

Fire may be applied as a management treatment. The biomass and the nitrogen and phosphorus pools are reduced to 5%.

During a model run the management may change up to five times.

### 2.1.6 Mowing subroutine

Name of the file : maaien.for  
First developed : 2006, for the quality project  
Changed : -  
Background document : Wamelink *et al.* (2008)  
Variables and parameters :

This subroutine simulates the effect of mowing on the vegetation. In mown grassland the leaf biomass of the functional type grasses/herbs is reduced to 1 ton•ha<sup>-1</sup>. The aboveground biomass of the other functional types is reduced to 0.002 ton•ha<sup>-1</sup>. The biomass of the roots is not reduced. The height of all functional types except for herbs/grasses is reduced to the height of their seedlings. For herbs/grasses the height is corresponding to the remaining biomass. The age of the shrubs and trees is set back to 1 year. The harvested biomass is removed from the system.

### 2.1.7 Grazing subroutine

Name of the file : animal.for  
First developed : 2001, for the grazing version of SUMO  
Changed : 2002, for the P version of SUMO; 2005, for SUMO 2.1  
Background document : Wamelink *et al.* (2001b), Wamelink *et al.* (2003c)  
Variables and parameters : [animal.xls](#)

The effect of grazing on the biomass development is modelled for fifteen different grazers. Grazers eat biomass which is subtracted from the biomass present in the organs of the functional types. A part of the eaten biomass is turned into body mass of the grazers and thus removed from the system. The larger part of the biomass is excreted. The different grazers do have their own diet, but this is also influenced by the availability of the biomass, i.e. a grazer may like to eat only leaves of grasses and herbs, but when a lot of leaves of dwarf shrubs are present it will eat more dwarf shrubs than it normally would. The density of grazers is partly fixed and partly allowed to range between limits. Domestic grazers do have a fixed density. Natural grazers density can range between zero and five times the initial density. The amount of available biomass for the grazers will determine the density, when there is enough food, the density will gradually raise till the maximum, when there is not enough food the density may gradually be lowered until it reaches (temporally) zero.

The amount of biomass available for the grazers depends on the height of the functional types and the present biomass. A minimum value is set for the biomass that can be eaten by grazers. This subroutine is activated from the management subroutine.

Calculation of the number of grazer units

$$GVE_t = ru_t + ho_t + jo_t + wi_t * 2 + pa_t + po_t + sc_t/5 + el_t + re_t/9 + ed_t/3 + da_t/4 + mo_t/5 + zw_t/4 \quad [2.1.7.1]$$

Calculation of the amount of available biomass, and the available biomass per organ.

$$bbb_{ijt} = bm_{ijt} - bmm_{ij} \quad [2.1.7.2]$$

For  $bbb_{ijt} < 0$ ;  $bbb_{ijt} = 0$

For  $lcb_t > 1,5$  m;  $bbb_{4,3t} = 1,5 * bl_{4,3t}$  and  $bbb_{5,3t} = 1,5 * bl_{5,3t}$

For  $lcb_t > 10$  m;  $bbb_{4,3t} = 0,1 * 1,5 * bl_{4,3t}$  and  $bbb_{5,3t} = 0,1 * 1,5 * bl_{5,3t}$

For cb or pb = coniferous tree;  $bbb_{4,3t} = 0,5 * 1,5 * bl_{4,3t}$  and  $bbb_{5,3t} = 0,5 * 1,5 * bl_{5,3t}$

$$bv_{jt} = bbb_{ijt} / \sum_{i=1,5} bm_{jt} \quad [2.1.7.3]$$

Correction of the grazers preferences for certain organs base don the food availability.

$$ev_{ijgt} = bv_{ijt} * vg_{ijg} / \sum_{i=1,5} \sum_{j=1,3} (bv_{ijt} * vg_{ijg}) \quad [2.1.7.4]$$

Calculation of the amount of biomass necessary for all grazers [2.1.12.5], calculation of the amount available [2.1.12.6] and the amount of eaten biomass [2.1.12.7 - 2.1.12.10].

$$ng_{ijgt} = ev_{ijgt} * vb_{ijgt} * aa_{gt} \quad [2.1.7.5]$$

$$no_{ijt} = \sum_{g=1,1,5} ng_{ijgt} \quad [2.1.7.6]$$

$$\text{For } bbb_{ijt} \geq no_{ijt}; gg_{ijgt} = no_{ijt} \quad [2.1.7.7]$$

$$\text{For } bbb_{ijt} < no_{ijt}; gg_{ijgt} = bbb_{ijt} * (ng_{ijgt} / no_{ijt}) \quad [2.1.7.8]$$

The shortage of one organ is added to the need for another organ.

$$ng_{i+1jgt} = ng_{i+1jgt} + (ng_{ijgt} - gg_{ijgt}) \quad [2.1.7.9]$$

When there is a shortage of eatable food for roots and/or wood this is added to the need for leaf biomass.

$$ng_{1,3gt} = ng_{1,3gt} + (ng_{5,jgt} - gg_{5,jgt}) \quad [2.1.7.10]$$

Due to the order in which food is divided for the grazers it is possible that there is still food available though the grazer has not eaten sufficient yet. To compensate for this the still available biomass is divided over the grazers that still have a need for food. To this purpose formula [2.1.12.5] is replaced by formula [2.1.12.12] and formula [2.1.12.6 - 2.1.12.9] is repeated.

Calculation of the still available biomass and calculation of the eaten biomass.

$$bbr_{ijt} = bbb_{ijt} - \sum_{g=1,1,5} gg_{ijgt} \quad [2.1.7.11]$$

$$ngr_{1,3gt} = ng_{5,3gt} - gg_{5,3gt} \quad [2.1.7.12]$$

The amount of wild grazers is adjusted for the food availability and lowered [2.1.12.13 - 2.1.12.14] or raised [2.1.12.15 - 2.1.12.16].

For  $ngr_{ijgt} - gg_{ijgt} > 0$

$$tg_{gt} = (\sum_{i=1,5, j=1,3} ng_g - \sum_{i=1,5, j=1,3} gg_{gt}) / \sum_{i=1,5, j=1,3} ng_g \quad [2.1.7.13]$$

$$aa_{gt+1} = aa_{gt} - (tg_{gt} * aa_{gt} * cl) \quad [2.1.7.14]$$

For  $\sum_{i=1,5, j=1,3, g=1,15} bbb_t > cb * \sum_{i=1,5, j=1,3, g=1,15} gg_t$

$$f = ch * (\sum_{i=1,5, j=1,3} bbb_t - \sum_{i=1,5, j=1,3} gg_t) / \sum_{i=1,5, j=1,3} ng_g \quad [2.1.7.15]$$

$$aa_{gt+1} = aa_{gt} + (aa_{gt} / \sum_{g=8,15} aa_t) * f \quad [2.1.7.16]$$

Correction of the biomass for eaten biomass

$$bm_{ijt} = bm_{ijt} - \sum_{g=1,15} gg_{ijt} \quad [2.1.7.17]$$

Calculation of the amount of faeces and the N-content and P-content

$$po_t = \sum_{i=1,5, j=1,3, g=1,15} (gg_t * pg_g) \quad [2.1.7.18]$$

$$np_t = \sum_{g=1,15} (nb_g * \sum_{i=1,5, j=1,3} gg_{gt}) / po_t \quad [2.1.7.19]$$

Where

- i = functional type; 1=herbs and grasses, 2=dwarf shrubs, 3=shrubs, 4=tree species 1, 5=tree species 2
- j = organ; 1=roots, 2=woody biomass, 3=leaves
- g = grazer; 1=rund, 2=Schotse hooglander, 3=jongvee, 4=wisent, 5=paard, 6=pony, 7=schaap, 8=eland, 9=ree, 10=edelhert, 11=damhert, 12=moeflon, 13=wild zwijn, 14=gans, 15=konijn
- t = tijdstip

ru = domestic cow, ho = 'wild cow', jo = young cow, wi = European Bison, pa = horse, po = pony, sc = sheep, el = moose, re = roe, ed = red deer, da = fallow deer, mo = moufflon, zw = wild boar (all in number of animals)

- aa = number of grazers
- bbb = available biomass for grazes per organ (ton/ha)
- bbr = available biomass for grazers per organ after the first division (in formulas [6 – 9] to be used in stead of bbb) (ton/ha)
- bl = leaf biomass per m and vegetation type (ton/ha/m)
- bm = biomass per organ (ton/ha)
- bmm = not available biomass for grazers per organ (ton/ha)
- bo = biomass per organ (ton/ha)
- bv = ratio of the biomass per organ
- cb = factor (1,1)
- ch = factor (0,5)
- cl = factor (1,2)
- ev = preference ratio of the eaten organ per grazer.
- f = factor for the change in grazer number
- gg = eaten biomass per organ and per grazer (ton/ha)
- lcb = height of tree species 2 (m)
- nb = N-content of the faeces per animal species

*ng* = amount of biomass needed per organ and grazer (ton/ha)  
*ngr* = amount of biomass needed per organ and grazer after the first division (ton/ha)  
*no* = biomass per organ before grazing (ton/ha)  
*np* = N-content of the total amount of faeces  
*pg* = mestgehalte van de gegeten biomassa per grazer  
*po* = total amount of faeces (ton/ha)  
*tg* = reduction of the number of grazers  
*vb* = amount of food needed per organ and per grazer (ton/ha)  
*vg* = initial ratio of organs eaten per grazer

### 2.1.8 The function Thinning\_amount

Name of the file : thinning\_amount  
 First developed : 2006, for the quality project  
 Changed : -  
 Background document : Wamelink *et al.* (2008)

This function initializes the thinning amount climax tree species dependent.

### 2.1.9 Age dependent mortality

Name of the file : age\_mor.for  
 First developed : 2006, for the quality project  
 Changed : -  
 Background document : Wamelink *et al.* (2008)

This subroutine simulates the mortality factor due to ageing and simulates whether or not a new tree species is chosen.

### 2.1.10 Balances subroutine

Name of the file : balansen.for  
 First developed : 2006, for the quality project  
 Changed : -  
 Background document : Wamelink *et al.* (2008)  
 Variables and parameters : [balansen.xls](#)

This subroutine controls the internal balances in SUMO for biomass ('carbon'), and all elements (N, P, K, Ca and Mg).

### 2.1.11 Biomass subroutine

Name of the file : biomassa.for  
 First developed : 2000, for  $\beta$  version SUMO  
 Changed : 2001, for the P version of SUMO; 2002, for the aging version of SUMO; 2004, for SUMO 2.0, 2005, for SUMO 2.1  
 Background document : Wamelink *et al.* (2000a), Wamelink *et al.* (2003c), Smart *et al.* , Wamelink *et al.* (2008)  
 Variables and parameters : [biomassa.xls](#)

From this subroutine the grasses subroutine is activated.

The biomass of each functional type is computed as the result of the biomass in the previous year, the newly grown biomass, the production of dead biomass and the amount of biomass removed by management. The newly grown biomass is the result of the reduction of the maximum growth of the functional type by the reduction factors for light interception, nitrogen availability, phosphorus availability and temperature. The effect of temperature may also raise the growth when the average yearly temperature is higher than the average for The Netherlands. The total biomass can also be reduced by the effects of management (see below). Each year, a small amount of biomass is added to each organ of each functional type to simulate seed input (0.0001 ton•ha<sup>-1</sup>•y<sup>-1</sup>). For several processes in SUMO the amount of biomass per organ is required. To this end the newly formed biomass is divided over the organs, where the division over the three organs differs per functional type. As for the total biomass the biomass per organ is corrected for death and management effects.

### 2.1.12 Grasses subroutine

Name of the file : grasses.for  
First developed : 2004, for SUMO 2.0  
Changed : -  
Background document : Smart *et al.*  
Variables and parameters : [grasses.xls](#)

The functional type grasses and herbs is split up in grasses, herbs and legumes. The division of the biomass is influenced by the management and based on the occurrence of grasses, herbs and legumes in the field [2.1.12.1]. We used the database of vegetation relevés present at Alterra for the Netherlands (with over 300,000 relevés) to estimate the presence of grasses, herbs and legumes for mowing frequency, grazing intensity (both translated into the Briemle/Ellenberg completed by Wamelink *et al* (unpublished) mowing indicator value) and nitrogen availability (translated from N availability into Ellenberg N). The regression between N-availability from SMART and Ellenberg N is specially estimated for this reason [2.1.12.2]. Legumes are nitrogen fixators. The nitrogen fixation in SUMO is simulated based on the regression estimated by Carlsson & Huss-Danell (2003) [2.1.12.3]. They found a linear relation between the legume biomass and the nitrogen fixed. The amount of fixed nitrogen is estimated based on the biomass in the previous year and then added to the amount of nitrogen allocated from the soil by the functional type grasses and herbs (and legumes), giving extra biomass. This subroutine is activated from the biomass subroutine.

Formula [2.1.12.1]

Fraction of grasses and legumes based on management intensity  
For mowing:

For no management : E\_M=1  
For mowing less then once a year : E\_M=2  
For mowing once a year : E\_M=3  
For mowing twice a year : E\_M=5  
For mowing three times a year : E\_M=6  
For mowing four times a year : E\_M=7  
For mowing five times a year : E\_M=8

For mowing six times a year : E\_M=8  
For mowing at least seven times a year : E\_M=9

For turf stripping  
E\_M=2

For forest management  
E\_M=1

for grazing

For GVE<=0.187497656 and E\_M<1: E\_M=1  
For GVE>0.187497656 and E\_M<2: E\_M=2  
For GVE>0.562492969 and E\_M<3: E\_M=3  
For GVE>0.937488281 and E\_M<4: E\_M=4  
For GVE>1.312483594 and E\_M<5: E\_M=5  
For GVE>1.687478907 and E\_M<6: E\_M=6  
For GVE>2.062474219 and E\_M<7: E\_M=7  
For GVE>2.437469532 and E\_M<8: E\_M=8  
For GVE>2.812464844 E\_M=9

Calculation of the fraction grasses, herbs and legumes based on management

For E\_M<1.5

$f_{gr\_M} = 0.333333333$   
 $f_{he\_M} = 0.333333333$   
 $f_{le\_M} = 0.333333333$

For E\_M>=1.5 and E\_M<2.5

$f_{gr\_M} = 0.576088$   
 $f_{he\_M} = 0.265003397$   
 $f_{le\_M} = 0.158908602$

For E\_M>=2.5 and E\_M<3.5

$f_{gr\_M} = 0.5015611$   
 $f_{he\_M} = 0.303323601$   
 $f_{le\_M} = 0.195115299$

For E\_M>=3.5 and E\_M<4.5

$f_{gr\_M} = 0.511306866$   
 $f_{he\_M} = 0.29865482$   
 $f_{le\_M} = 0.190038314$

For E\_M>=4.5 and E\_M<5.5

$f_{gr\_M} = 0.506198899$   
 $f_{he\_M} = 0.257848538$   
 $f_{le\_M} = 0.235952563$

For E\_M>=5.5 and E\_M<6.5

$f_{gr\_M} = 0.52433065$   
 $f_{he\_M} = 0.220026562$   
 $f_{le\_M} = 0.255642788$

For E\_M>=6.5 and E\_M<7.5

$f_{gr\_M} = 0.540960823$   
 $f_{he\_M} = 0.167929465$   
 $f_{le\_M} = 0.291109712$   
 For  $E\_M \geq 7.5$  and  $E\_M < 8.5$   
 $f_{gr\_M} = 0.588492669$   
 $f_{he\_M} = 0.137044$   
 $f_{le\_M} = 0.274463331$

For  $E\_M \geq 8.5$   
 $f_{gr\_M} = 0.576470588$   
 $f_{he\_M} = 0.423529411$   
 $f_{le\_M} = 0.000000001$  (for practical reasons)

Calculation of Ellenberg N

[2.1.9.2]

For non forests

$$E\_N = ((N_{avail} * 1000) - 8.125) / 16.25$$

For forests

$$E\_N = ((N_{avail} * 1000) - 8.125) / 30$$

Fraction of grasses, herbs and legumes based on nitrogen availability

For non forest

For  $E\_N < 1.5$

$$f_{gr\_N} = 0.428959021$$

$$f_{he\_N} = 0.438277668$$

$$f_{le\_N} = 0.132763311$$

For  $E\_N \geq 1.5$

$$f_{gr\_N} = 0.466964332$$

$$f_{he\_N} = 0.38346433$$

$$f_{le\_N} = 0.1495713391$$

For  $E\_N \geq 2.5$

$$f_{gr\_N} = 0.474258742$$

$$f_{he\_N} = 0.289501266$$

$$f_{le\_N} = 0.236239991$$

For  $E\_N \geq 3.5$

$$f_{gr\_N} = 0.473021943$$

$$f_{he\_N} = 0.270223738$$

$$f_{le\_N} = 0.256754319$$

For  $E\_N \geq 4.5$

$$f_{gr\_N} = 0.482387527$$

$$f_{he\_N} = 0.236735892$$

$$f_{le\_N} = 0.280876581$$

For  $E\_N \geq 5.5$

$$f_{gr\_N} = 0.53178222$$

$$f_{he\_N} = 0.221913139$$

$$f_{le\_N} = 0.246304641$$

For  $E\_N \geq 6.5$

$$f_{gr\_N} = 0.556095724$$

$$f_{he\_N} = 0.250714481$$

$$f_{le\_N} = 0.193189795$$

For  $E_N \geq 7.5$

$$\begin{aligned}f_{gr_N} &= 0.407153844 \\f_{he_N} &= 0.25663796 \\f_{le_N} &= 0.336208196\end{aligned}$$

For forest

For  $E_N < 1.5$

$$\begin{aligned}f_{gr_N} &= 0.680410817 \\f_{he_N} &= 0.280215156 \\f_{le_N} &= 0.039374027\end{aligned}$$

For  $E_N \geq 1.5$

$$\begin{aligned}f_{gr_N} &= 0.594570231 \\f_{he_N} &= 0.345741342 \\f_{le_N} &= 0.059688428\end{aligned}$$

For  $E_N \geq 2.5$

$$\begin{aligned}f_{gr_N} &= 0.571099619 \\f_{he_N} &= 0.297616697 \\f_{le_N} &= 0.131283684\end{aligned}$$

For  $E_N \geq 3.5$

$$\begin{aligned}f_{gr_N} &= 0.532109887 \\f_{he_N} &= 0.301303743 \\f_{le_N} &= 0.16658637\end{aligned}$$

For  $E_N \geq 4.5$

$$\begin{aligned}f_{gr_N} &= 0.465259263 \\f_{he_N} &= 0.312078359 \\f_{le_N} &= 0.222662377\end{aligned}$$

For  $E_N \geq 5.5$

$$\begin{aligned}f_{gr_N} &= 0.422651303 \\f_{he_N} &= 0.316431663 \\f_{le_N} &= 0.260917034\end{aligned}$$

For  $E_N \geq 6.5$

$$\begin{aligned}f_{gr_N} &= 0.325841496 \\f_{he_N} &= 0.334189754 \\f_{le_N} &= 0.33996875\end{aligned}$$

For  $E_N \geq 7.5$

$$\begin{aligned}f_{gr_N} &= 0.253907377 \\f_{he_N} &= 0.400329878 \\f_{le_N} &= 0.345762745\end{aligned}$$

Calculation of the final fraction

$$\begin{aligned}f_{gr} &= (f_{gr_M} * f_{gr_N}) / (f_{gr} + f_{he} + f_{le}) \\f_{he} &= (f_{he_M} * f_{he_N}) / (f_{gr} + f_{he} + f_{le}) \\f_{le} &= (f_{le_M} * f_{le_N}) / (f_{gr} + f_{he} + f_{le})\end{aligned}$$

Nitrogen fixation by legumes

[2.1.9.3]

For  $gr_{le} < 0.100001$ ;  $Nfix = 0.01 * gr_{le}$

For  $gr_{le} > 0.1$ ;  $Nfix = 0.0073 + 0.01 * gr_{le}$



Where:

E\_M : Briemle/Ellenberg indicator value for mowing/management intensity  
(Wamelink unpublished)  
GVE : number of grazer units  
f<sub>gr\_M</sub> : fraction of grasses based on management  
f<sub>he\_M</sub> : fraction of herbs based on management  
f<sub>le\_M</sub> : fraction legumes based on management  
f<sub>gr\_N</sub> : fraction of grasses based on Ellenberg N  
f<sub>he\_N</sub> : fraction of herbs based on Ellenberg N  
f<sub>le\_N</sub> : fraction legumes based on Ellenberg N  
f<sub>gr</sub> : fraction of grasses  
f<sub>he</sub> : fraction of herbs  
f<sub>le</sub> : fraction legumes  
gr<sub>le</sub> : growth legumes (ton/ha)  
Nfix : amount of nitrogen fixated (ton/ha)

### 2.1.13 The final element uptake

Name of the file : final\_opname.for  
First developed : 2006, for the quality project  
Changed :-  
Background document : Wamelink *et al.* (2008)

This subroutine calculates the finale element uptake, corrected for the surplus of uptake due to lower availability of another element.

### 2.1.14 Element content subroutine; steering subroutine

Name of the file : CNverh.for  
First developed : 2000, for  $\beta$  version SUMO  
Changed : 2001, for the validation; 2001, for the P version of SUMO;  
2002, for the dead wood version of SUMO; 2002, for the aging  
version of SUMO  
Background document : Wamelink *et al.* (2000a), Wamelink *et al.* (2001a), Wamelink *et al.* (2003c), Wamelink *et al.* (2003e), Wamelink *et al.* (2008)  
Variables and parameters : [CNverh.xls](#)

This subroutine simulates the element budgets for the organs and functional types, as well as the reallocation of nitrogen.

The newly taken up element is divided over the organs. The element content in the organs is calculated after adding the new biomass and new element, and subtracting litterfall and the element left in it. Part of the nitrogen of the dead biomass is reallocated and is added to the available nitrogen in the next year. The amount of reallocated nitrogen depends on the organ and the nitrogen content of the organ. When the nitrogen content is lower than a threshold value no nitrogen is reallocated.

Each year part of the biomass dies. The fraction that dies depends on the organ and the functional type, and varies from 1.0 for leaves of herbs, shrubs and deciduous trees to 0.01 for stems of climax trees. The actual element content is calculated in a separate subroutine (el\_content.for) and is called from this subroutine.

### **2.1.15 Element content**

Name of the file : el\_contents.for  
First developed : 2006, for the quality project  
Changed : -  
Background document : Wamelink *et al.* (2008)

This subroutine calculates the element content of the organs and is called from the CNverh.for subroutine.

### **2.1.16 The function tree index**

Name of the file : tree\_index  
First developed : 2006, for the quality project  
Changed : -  
Background document : Wamelink *et al.* (2008)

This function returns 0 or 1 for tree species. When it returns 1 age mortality starts.

### **2.1.17 Effect of carbon dioxide concentration**

Name of the file : COtwo.for  
First developed : 2006, for the quality project  
Changed : -  
Background document : Wamelink *et al.* (2008)

This subroutine calculates the effect of changing carbon dioxide concentration on the maximum growth rate. This function makes the input of Gmax (from parameter.txt and boomparamete.txt) superfluous. However, it is still read as input.

### **2.1.18 Subroutine element uptake**

Name of the file : El\_opname.for  
First developed : 2001, for the P version of SUMO  
Changed : 2005, for SUMO 2.1, 2006 for the quality project  
Background document : Wamelink *et al.* (2003c), Wamelink *et al.* 2008  
Variables and parameters : Popname.xls

This subroutine simulates the element uptake of the functional types. It is basically the same as for nitrogen uptake, except that there is no reallocation term and no foliar uptake.

### 2.1.19 LAindex subroutine

Name of the file : LAindex.for  
First developed : 2001, for the grazing version of SUMO  
Background document : Wamelink *et al.* (2001b)  
Variables and parameters : LAindex.xls

The Leaf area index is calculated in the simplest way, based on the leaf biomass simulated in SUMO. The simulation was originally added for the interaction with SAWPlite (Groenedijk *et al.* 1999). SUMO provided SWAPlite with the LAI. Now the LAI can also be used for comparison with data obtained with Remote Sensing. The LAI is calculated differently for three different vegetation groups. For all the LAI depends on the leaf biomass simulated by SUMO. For grassland, heathland, reed, salt mars swamps and peat formula [2.1.19.1] is applied, for deciduous forest formula [2.1.19.2] and for coniferous forest formula [2.1.19.3].

$$\text{LAI}_t = (0,4425 * \text{bt}_t) - 0,3982 \quad [2.1.19.1]$$

$$\text{LAI}_t = \text{bt}_t \quad [2.1.19.2]$$

$$\text{LAI}_t = 0,5 * \text{bt}_t \quad [2.1.19.3]$$

For all  $\text{LAI}_t < 0,1$ ;  $\text{LAI}_t = 0,1$

where:

LAI : Leaf Area Index at time t  
bt : total leaf biomass (ton/ha)  
t : time (y)

Formula [2.1.19.1] is adapted from Cusack *et al.* (1999), the other two are based on expert knowledge (pers. comm P. Groenedijk).

### 2.1.20 Height subroutine

Name of the file : lengte.for  
First developed : 2000, for  $\beta$  version SUMO  
Changed : 2001, for the grazing version of SUMO; 2001, for the aging version of SUMO  
Background document : Wamelink *et al.* (2000a), Wamelink *et al.* (2001b), Wamelink *et al.* (2008)  
Variables and parameters : lengte.xls

The height of the five functional types is calculated each year. As height growth is assumed to decline with age, SUMO also keeps track of the 'age' (i.e., the number of years since colonisation or plantation occurred) per functional type. For the functional types herbs/grasses and dwarf shrubs the height is based on the biomass present in the functional type.

The height of shrubs is calculated. It depends on the age of the stand. Over the years the height growth is decreasing until the maximum height has been reached.

The computation of the height of the trees is more complicated. It is based on the height in the previous year, the biomass growth in the current year, a minimum and maximum height

growth, and the 'age' of the functional type. The maximum and minimum height growth of the trees is based on growth curves for the Netherlands on rich and poor soil, respectively (Jansen *et al.* 1996). The realised height growth per tree species per year lies between values determined by the growth curves at the tree's 'age' and the biomass increment in that year, according to. The height growth of shrubs and trees is assumed to start at a given threshold biomass (0.15 ton•ha<sup>-1</sup> for the sum of stem biomass of shrubs and trees; the threshold values are equal to the threshold values for succession. If the biomass is below this threshold the height is set to the minimum height given above, and the age is reset to 1 year. A maximum height is explicitly imposed only for dwarf shrubs (1 m). The height and the height growth of the functional types are also influenced by management (see below).

### 2.1.21 The function iboom

Name of the file : iboom  
 First developed : 2006, for the quality project  
 Changed : -  
 Background document: Wamelink *et al.* (2008)

This function returns an integer tree species dependent. The integer is used in the subroutine `lengte.for` instead of the character value.

### 2.1.22 Light subroutine

Name of the file : licht.for  
 First developed : 2000, for  $\beta$  version SUMO  
 Changed : 2001, for the grazing version of SUMO  
 Background document : Wamelink *et al.* (2000a), Wamelink *et al.* (2001b)Wamelink *et al.* (2008)  
 Variables and parameters : [licht.xls](#)

The interception of light is simulated assuming an exponential decrease of light intensity with decreasing height within the canopy, using the Lambert-Beer equation; (cf. Huisman & Weissing 1994). The light interception per functional type is based on the biomass and position of the leaves. For each functional type the leaves are considered to be equally distributed over the height of the functional type, except for trees higher than 7m, where the canopy does not start at the ground level but at a height of 1.5m. In total five canopy layers are distinguished in which at least one and at most five functional types are present. The highest layer starts at the top of the highest functional type and ends at the height of the second highest functional type. It contains a fraction of the leaf biomass of the highest functional type proportional to the thickness of the layer relative to the height of the functional type. The light that is not intercepted is passed to the next layer. The second layer consists of two functional types, the highest and the second highest, and this layer ends at the height of the third highest functional type. The leaf biomass of the two functional types in this layer is again computed, and added to give the total leaf biomass for the layer. The light interception computed on the basis of this total biomass is subsequently divided over the two functional types according to their proportion in the total leaf biomass in that layer. The light interception of the functional types in the other three layers is calculated in a similar way. Per functional type the interception of the layers is summed to give the total light interception. Atmospheric nitrogen is assumed to be taken up by the canopy, with a rate that declines exponentially with height. For the sake of simplicity the deposition is distributed over the functional types proportional to their light interception. Data on atmospheric deposition comes from external

sources (i.e. deposition models or maps). The actual available atmospheric nitrogen for the vegetation is calculated by SMART2 and depends on the structure of the vegetation (forests catch more deposition than grasslands).

### 2.1.23 The function FT\_height

Name of the file : FT\_height  
First developed : 2006, for the quality project  
Changed : -  
Background document : Wamelink *et al.* (2008)

This function calculates the height rank of the functional types. This is used in the subroutine licht.for to calculate the light interception per functional type.

### 2.1.24 N uptake subroutine

Name of the file : Nopname.for  
First developed : 2000, for  $\beta$  version SUMO  
Changed : 2001, for the P version of SUMO; 2005, for SUMO 2.1  
Background document : Wamelink *et al.* (2000a), Wamelink *et al.* (2003c)  
Variables and parameters : [Nopname.xls](#)

In SUMO, nitrogen comes from three sources:

1. uptake from the soil,
2. atmospheric deposition,
3. internal reallocation from one organ to another.

(1) The nitrogen release from the soil and litter is simulated by SMART2. The fraction of soil nitrogen absorbed by each functional type is assumed to be equal to the proportion of its root biomass in the total root biomass. The total nitrogen availability for each functional type is calculated by summing (1), (2) and (3).

The influence of the nitrogen availability on the growth of each functional type is described by a saturation equation based on potential growth, total nitrogen availability, and the minimum nitrogen content per functional type. In principle, all available nitrogen is taken up, but the nitrogen uptake of each functional type is limited by its maximum growth and maximum nitrogen content. The nitrogen that is not taken up by the roots remains in the soil.

### 2.1.25 Temperature subroutine

Name of the file : T.for  
First developed : 2004, for SUMO 2.0  
Changed : for the forest focus project 2006  
Background document : Smart *et al.* , Wamelink *et al.*(2008)  
Variables and parameters : [T.xls](#)

The effect of temperature was originally calculated based on the Q10. However for the forest focus project the whole subroutine was changed. Now the effect of temperature on the maximum growth is based on Lieth (1975). For tree species the effect is species specific, for all other functional types the same regression is used. The potential growth of the functional

types is either raised or lowered compared with the standard average temperature in The Netherlands (9.8°C).

### 2.1.26 Output subroutine

Name of the file : -  
First developed : 2000, for  $\alpha$  version SUMO  
Background document : Wamelink *et al.* (2000a)  
Variables and parameters : [uitvoer.xls](#)

This subroutine calculates input for SMART that is denoted in different units.

Calculation for biomass from ton/ha/y to kg/m<sup>2</sup>/y is done by dividing the amount by 10.  
Calculation of the actual uptake of nitrogen and phosphorus from ton/ha/y to molc/m<sup>2</sup>/y is done by multiplying the amount with 100/14 for nitrogen and 100/31 for phosphorus.

### 2.1.27 Vegetation subroutine

Name of the file : vegtype.for  
First developed : 2000, for  $\beta$  version SUMO  
Changed : 2002, for the quality project 2006  
Background document : Wamelink *et al.* (2000a), Wamelink *et al.* (2008)  
Variables and parameters : [vegtype.xls](#)

After succession takes place (see 2.1.2) this subroutine is activated. It determines in what new vegetation type the vegetation succeeds. The succession is based on the amount of biomass present in the functional types and soil type and groundwater table (the latter two only for forest). When succession to forest takes place two tree species are selected based on present soil type and groundwater table. The succession schemes and conditions are given in table [2.1.13A](#). The subroutine Larchvegtype (see 2.1.14) is activated from this subroutine.

### 2.1.28 Larchvegtype subroutine

Name of the file : -  
First developed : 2000, for  $\beta$  version SUMO  
Changed : 2005, for the quality project 2006  
Background document : Koolstra *et al.* (1999), Wamelink *et al.* (2005), Wamelink *et al.* (2008).  
Variables and parameters: [Larchsuccessie.xls](#)

This subroutine is still incorporated in the vegetation subroutine. It changes the LARCH vegetation type when succession to a new vegetation type occurs. The LARCH vegetation type is not used in SUMO or SMART. It is output and can be used by the model LARCH. The translation from SUMO vegetation types into LARCH vegetation types is given in table [2.1.14A](#).

### 2.1.29 The function codesoil

Name of the file : codesoil  
First developed : 2006, for the quality project  
Changed :-  
Background document : Wamelink *et al.* (2008)

This function returns an integer for the soil code (provided by SMART2). It is used in vegtype.for for the succession of the vegetation.

### 2.1.30 The function codeLARCH

Name of the file : codelarch  
First developed : 2006, for the quality project  
Changed :-  
Background document : Wamelink *et al.* (2008)

This function returns an integer for the LARCH code. It is used in LARCHsuccessie.for for the succession of the vegetation.

### 2.1.31 Moist subroutine

Name of the file : vocht.for  
First developed : 2000, for  $\beta$  version SUMO  
Changed : 2003, for the evaporation version of SUMO  
Background document : Wamelink *et al.* (2004a)  
Variables and parameters : vocht.xls

Initially the effect of water availability for the vegetation was based on the mean groundwater table. In 2003 this was changed. The growth of the functional types is now depended on the available water and the potential evaporation of the present vegetation type. The functional types do not (yet) compete with each other for water. The potential growth of each functional type is reduced with a factor depending on the ratio between the potential evaporation and the actual evaporation by the vegetation. The latter is calculated by SMART2. The moment succession takes place from one vegetation type to another the evaporation may also change. The change of evaporation is modelled to last ten years (using a calculated a linear relation).

## 2.2 Coherence of the subroutines

The above described subroutines exchange information on a yearly basis as shown in fig. 2.1.1 – 2.1.3. The simulation of the processes is depicted in figuur 2.2.1.

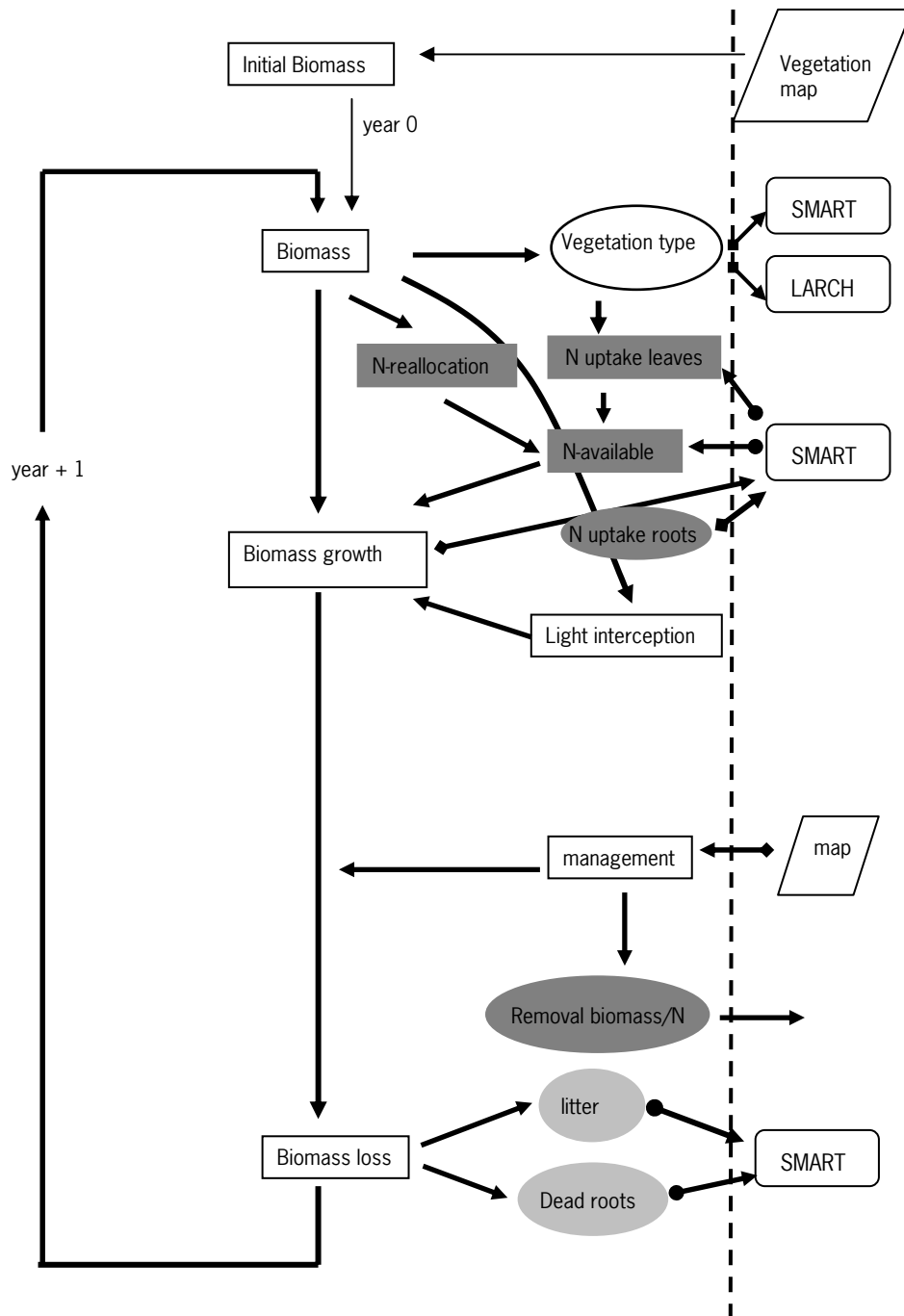


Figure. 2.2.1. Flow diagram of SUMO, including the link with SMART2, maps and iniSUMO. A rectangular indicates a process in SUMO, an oval indicates output. Arrows depict the information flow ( —→ SUMO in, ●→ SUMO out). The uncolored diagrams indicate processes linked to biomass, the dark ones indicate nitrogen processes, and the light gray ones indicate processes linked to decay.



## 2.3 Description of the standard program for making the 'Natuurplanner' database

SUMO2 uses several input files containing parameters. These are delivered together with the executable including SMART2 and SUMO2. The executable can be incorporated in the Natuurplanner and all the files must be placed in the specified map.

## 2.4 Communication with SMART2

SUMO2 is linked to SMART2 and depends on information from SMART2. SUMO2 also delivers information to SMART2. Besides the initialisation phase SUMO2 and SMART2 exchange data twice each time step of one year; once from SMART2 to SUMO2 and once of the end of the SUMO2 run from SUMO2 to SMART2 (see also fig. 2.1.2).

The data exchange in the initialisation is given in table 2.4.1.

*Table 2.4.1. Data exchanged between SMART2 and SUMO2. Input is input from SMART2 or from inputfiles, output is output to SMART2 or to output files, if none of them is marked then the data is only exchanged with the interface for use in the next year.*

Parameter	Explanation	Input	Output	Unit
Sustart	Indicator if it is a initialisation year			-
ijaar	runtime	*		y
iyr	year			y
CodeDir				
pboom	Tree species 1 (pioneer tree)		*	-
cboom	Tree species 2 (climax tree)		*	-
bodemtype	Soil type	*		-
larchfilenr	Vegetation type for LARCH		*	-
leeftijd	Age of tree species			Y
gvg	Spring groundwater table	*		M
avg_t	Average temperature	*		°C
pCO <sub>2</sub> a	CO <sub>2</sub> concentration	*		Ppm
vegtype	vegetationtype	*	*	-
filenr	File number	*	*	-
beheer1	management	*		-
plaggen	Sod cutting frequency	*		y
maaien	mowing	*		-
bemesting	manuring	*		Ton/ha
aantal	Number of grazers	*		-
strooisel	Sod cutting in first year	*		-
Padmax	Check for P in run included	*		-
sm_dbladtot	Amount of dead leaves		*	Kg/m <sup>2</sup>
smarttak	Amount of dead wood		*	Kg/m <sup>2</sup>
sm_dworteltot	Amount of dead roots		*	Kg/m <sup>2</sup>
smartblad	Amount of leaves		*	Kg/m <sup>2</sup>
amex	Amount of excrements		*	Kg/m <sup>2</sup>
sm_doodhouttot	Total amount of dead wood		*	Kg/m <sup>2</sup>
Ngeh_dwtot	Nitrogen content of dead roots		*	-
Pgeh_dwtot	Phosphorus content of dead roots		*	-
Cageh_dwtot	Calcium content of dead roots		*	-
Mggeh_dwtot	Magnesium content of dead roots		*	-
Kgeh_dwtot	Potassium content of dead roots		*	-
Ngeh_dbtot	Nitrogen content of dead leaves		*	-
Pgeh_dbtot	Phosphorus content of dead leaves		*	-
Cageh_dbtot	Calcium content of dead leaves		*	-
Mggeh_dbtot	Magnesium content of dead leaves		*	-
Kgeh_dbtot	Potassium content of dead leaves		*	-
Ngehaltepoep	Nitrogen content of excrements		*	-
Pgehaltepoep	Phosphorus content of excrements		*	-
Cagehaltepoep	Calcium content of excrements		*	-

Parameter	Explanation	Input	Output	Unit
Mggehaltepoep	Magnesium content of excrements		*	-
Kgehaltepoep	Potassium content of excrements		*	-
Ngeh_dhtot	Nitrogen content of dead wood		*	-
Pgeh_dhtot	Phosphorus content of dead wood		*	-
Cageh_dhtot	Calcium content of dead wood		*	-
Mggeh_dhtot	Magnesium content of dead wood		*	-
Kgeh_dhtot	Potassium content of dead wood		*	-
tnituptmx	Nitrogen availability	*		Mol/m <sup>2</sup>
tPuptmx	Phosphorus availability	*		Mol/m <sup>2</sup>
tCauptmx	Calcium availability	*		Mol/m <sup>2</sup>
tMguptmx	Magnesium availability	*		Mol/m <sup>2</sup>
tKuptmx	Potassium availability	*		Mol/m <sup>2</sup>
opnamegr	Amount of nitrogen taken up by the vegetation		*	mol/m <sup>2</sup>
P_opnamesmart	Amount of phosphorus taken up by the vegetation		*	mol/m <sup>2</sup>
Ca_opnamesmart	Amount of calcium taken up by the vegetation		*	mol/m <sup>2</sup>
Mg_opnamesmart	Amount of magnesium taken up by the vegetation		*	mol/m <sup>2</sup>
K_opnamesmart	Amount of potassium taken up by the vegetation		*	mol/m <sup>2</sup>
biomt_param_smart	Total biomass for SMART vegetation types		*	Kg/m <sup>2</sup>
biom	Biomass per functional type and organ			Ton/ha
Ngeh_org	Nitrogen content of the organs			-
Pgeh_org	Phosphorus content of the organs			-
lengte	Height of the functional types		*	m
gegetentot	Total amount of biomass eaten		*	Ton/ha
nh4fu	Leaf interception of nitrogen			Mol/m <sup>2</sup>
tr	Maximum evaporation	*		Mm
LAI	Leaf area index		*	m/m
evap_potwb	Maximum evapotranspiration by watball		*	Mm
GrRed	Growth reduction factor		*	-
GrRed_m	Growth reduction factor for moist		*	-
GrRed_l	Growth reduction factor for light		*	-
xcoord	X coordinate	*		M
ycoord	Y coordinate	*		M
opp	Surface of the plot	*		Ha*10
afvoerbiom	Amount of biomass removed from the system		*	Ton/ha
growth_w	Growth wood		*	Ton/ha
ErrorNumber	Error message number			-
PError	Error message			-

## **3 Sensitivity and uncertainty analyses, calibration and validation of SUMO**

### **3.1 Sensitivity and uncertainty analyses**

SUMO has been the subject of two separate analyses. The first was carried out for the model chain SMART2-SUMO2-NTM4 by Schouwenberg *et al.* (2000). The second was carried out for SUMO alone (Wamelink 2008, WOt-werkdocument 98). A sensitivity and uncertainty analyses of the model chain soilmap-SMART2-SUMO2-MOVE3 is being carried out at the moment. The first analyses showed that compared to the other model uncertainties the uncertainty in caused by SUMO2 was small. The second analyses showed that for grassland the maximum growth speed for grasses and herbs, the light interception and factor that gives the amount of dead roots determine for over 85% the simulated total biomass in grassland when the management consists of mowing once a year.

### **3.2 Validation of SUMO2**

See SMART *et al.* (2005), Wamelink (2007), de Vries *et al.* (2007) and Wamelink *et al.* (2008a). SUMO2 is not validated for the vegetation types salt marsh, coppice sites and swamps. Use this vegetation types with great care. The effect of grazers is difficult to validate. Only the effects of sheep and cows is validated. For all other grazers no validation has been carried out. Note that for most parameters values from literature are used to estimate the parameter values.

Results of the validations showed that the prediction of biomass development in grasslands and heathlands is quite good. The results were less good for some stages in forest growth on two plots for the Netherlands. On a European scale the growth simulation in forest was quite good, after site specific parameterization of SMART2 and overall parameterization of SUMO2. The predictions of nitrogen content in the leaves was adequate.

### **3.3 Calibration of SUMO2**

Up till present day SUMO2 is calibrated base don expert judgement (G.W.W.Wamelink and J.P. Mol-Dijkstra). The parameter values are based on field data, when available, and are fine tuned to get acceptable results. Not all parameters are subjected to fine tuning. Only the maximum growth rate (very few field data), light interception factor (very few field data) and maximum and minimum element content (all elements, but mostly N) are used for fine tuning. For the minimum and maximum content lots of data are available, and parameter values are fine tuned around the 5 and 95 percentiles of the element contents found in the field.

SUMO2 is normally not fine tuned for site specific applications, although in principle it is possible, as was partly shown for the EU simulations of forests on sites with site specific data (Wamelink *et al.* 2008).



## 4 Model application technical

This chapter shows how SUMO2 could be run, what files are necessary, what the limits in the input are and states briefly what combinations are legitimate as input for SUMO2. Mark that SUMO2 can not be run without SMART2. The input for SMART and the boundaries for that model are described elsewhere (Mol *et al.* ).

### 4.1 Installation files for SUMO2 v 3.2

SUMO requires several types of input files for proper functioning. Some of these files contain parameter values, which may not be changed by the user; they are given in this paragraph. Input files that contain site specific information are described in paragraph 3.3.

Necessary files for SUMO containing parameter values (only to be changed by model developers!).

#### [Biomini.txt](#)

The file contains the initial biomass and initial N content per organ and per vegetation structure type (filenr).

#### [Biommin.txt](#)

The file contains the values for the minimum of biomass that is required per organ before grazers can eat from the biomass.

#### [Boomparamete.txt](#)

This file contains parameters for the division of new biomass and nitrogen over the organs, the added amount of seed biomass in the system per organ, the fraction of dead biomass per organ, the light extinction factor, the minimum and maximum N content, the minimum and maximum P content and the maximum growth rate. All only for tree species, separated for each species modelled!

#### [Dunning.txt](#)

This file contains the cutting cycle period and the percentage of thinning per thinning cycle and tree species.

#### [Graas.txt](#)

This file contains parameters about the amount of biomass required for one animal and the fraction of preference for each combination of organ and functional type.

#### [LARCHsuccessie.txt](#)

This file contains the succession scheme for LARCH types.

#### [Lengteparam.txt](#)

This file contains parameters for the calculation of the height growth per tree (the actual height depends also on the biomass increment).

### [Paramete.txt](#)

This file contains parameters for the division of new biomass and nitrogen over the organs, the added amount of seed biomass in the system per organ, the fraction of dead biomass per organ, the light extinction factor, the minimum and maximum N content, the minimum and maximum P content and the maximum growth rate. The parameters are given for the functional types grasses and herbs, dwarf shrubs and shrubs per vegetation type.

### [Poep.txt](#)

This file contains parameters for the amount of biomass eaten by each grazer, the fraction that become excreted, and the N and P contents of the faeces and ureum.

### [SUMOleeftijdsuccessie.txt](#)

This file contains a succession scheme for the ageing of forest; it changes the file number, which also includes information about the age of the stand.

### [SUMOsuccessie\\_fnr.txt](#)

This file contains information of the succession in SUMO

### [Terugtre.txt](#)

This file contains the fraction of N that is reallocated depending on the N content of the organ per organ.

### [Tgrowth.txt](#)

This file contains information about the parameters influencing the maximum growth rate due to variable temperatures

### [Transpiration.txt](#)

This file contains information about the maximum evaporation for The Netherlands.

### [Tree\\_mortality.txt](#)

This file contains parameter values used for the tree mortality per organ.

## **4.2 Changeable input files for SUMO2 v .3.2.1**

### **Vegout.txt**

An example of the vegetation input file for SUMO2 is given in table [Appendix\\*](#) (Table 4.2.1). Please, use the vegetation type swamp in this version of SUMO2 with great reserve, since it is not fully calibrated and tested yet.

If you combine a non-forest structure type with a tree species, succession will not occur properly. As to the forest structure types in principle all combinations of trees is possible, but it is of course quite strange to define a beech forest without beech being given as at least one of the tree species. A combination of twice the same tree species is also an option.

All the columns shown in [Appendix\\*](#) are obligatory. The x and y coordinate gives the position of the grid and must be the same as the initialisation file for SMART and the extra\_manag.txt file. This is controlled by the model! The surface is the surface of the vegetation type in the cell and of no consequence in the models. The amount of manure (in N ton/ha) is given in the next column, it will become available for the vegetation each year and is not subjected to the mineralization process in SMART. The vegetation type (see table 4.2.4, for the 17 different

types) is given as a number and rules the parameters (derived from other input tables) for many processes. The explanation for the numbers used for the Management is given in the chapter on the boundaries. The frequency gives the interval the management is applied (1 = every year, 10 = once every 10 years). The column litter removal is not in use at the moment. The mowing frequency is given in the times per year, with a minimum of 1 and a maximum of 9. The stand age is used for the initialisation of the forests and the thickness of the litter layer for all vegetation types. Tree species 1 and 2 may be given from the start (in a three letter code, in Dutch, in total 15 species, see table 4.2.3) or be picked by the model at the moment succession is simulated. The LARCH vegetation type is output from SUMO for the model LARCH, and finally 15 columns for the initialisation of the grazers (per grazer see table 4.2.5 and 4.2.6). When the number equals zero then that grazer will never be present, unless it is changed in extra\_manag.txt. Non domestic grazers that are present at the initialisation may become zero at a certain period during the simulation when there is not enough food to consume. See also Table 4.2.1 for an overview.

Table \*. 4.2.1. Code units and range for the input file vegout.txt.

short	Explanation	Unit	Range
Xcoord	X coordinate	m	
Ycoord	Y coordinate	m	
p	Surface area	m <sup>2</sup>	
m	manure	Ton/ha	>= 0
veg	Vegetation type (see table 4.2.4)	-	1 - 17
beh	management	-	0 - 9
pla	Sod cutting frequency	y	>= 0
str	Sod cutting in first year	-	0 or 1
x	Management frequency	/y	>=0
fil	File number (see Table 4.2.6)	-	1 - 59
Pbo	Tree species 1 (see 4.2.6)	-	
Cbo	Tree species 2 (see 4.2.6)	-	
lar	LARCH vegetation type (see LARCH, Poewels <i>et al.</i> in prep)	-	-
Grazers (15)	See Table 4.2.5	/ha	>= 0

### Extra\_manag.txt

An example for the extra management file for SUMO is given in [Appendix](#) (see table 4.2.2 for an explanation of the input).

This file gives the possibility to change the management up to five times during the model run. The change takes place depending on the year that is given in year (jaar) column. All types of management available in SUMO may be changed during the model run (within its boundaries). The layout is comparable with the vegout.txt input file, but contains only the columns that can be changed during the model run. The file will be opened by SUMO and has to be present in the same directory as the other files, also when no management change during the run is necessary. The management may be changed five times. The column 'year' rules when the management is changed (to be given as the run year before change must take place). When less than five management changes are necessary then the 'year' column of the remaining management options must be set to -99. All columns must be filled, even for years with -99, with an integer, except for grazing, which may be a real as well. The x en y coordinates must be given at the start, SUMO controls whether they are equal to the x and y coordinates of the vegetation input file for SUMO. The complete input for the first management change is: x-coordinate, y-coordinate, manure (ton/ha/y), management, frequency, mowing frequency, year, cow, wild cow, young cow, European bison, pony, horse, sheep, moose, deer, red deer, fallow deer, moufflon, wild boar, goose, rabbit. For the management changes 2 – 5 the manure till rabbit columns are repeated. All entries in the columns must be given in the conventions for SUMO.

Table 4.2.2. Code units and range for the input file *extra\_manag.txt*. The given sequence is repeated five times.

short	Explanation	Unit	Range
Xcoord	X coordinate	m	
Ycoord	Y coordinate	m	
bem	manure	Ton/ha	>= 0
beheer	management	-	0 – 9
plaggen	Sod cutting frequency	y	>= 0
maaien	Management frequency	/y	>=0
jaar			
Grazers (15)	See Table 4.2.5	/ha	>= 0

### Boundaries for the input parameters for the vegetation

In this paragraph the boundaries of the variables for the files *vegout.txt* and *extra\_manag.txt* are described. The input variables have to be given in the files; the exact sequence of the variables has been described in the previous paragraphs.

The file [boundaries site specific input data SUMO.xls](#) gives the variables and the limits for each input variable in *vegout.txt*. Though the limits are described in this table not all combination of the input variables given in the table are legitimate. Limitation for the possible combination are present for combinations of vegetation type and file number, management and frequency and mowing frequency, stand age and file number . Moreover litter removal must always be set to 0.

Rules for the combination of management, frequency and mowing frequency are as follows:

1. Management '0' (no management) does not refer to frequency or mowing frequency, therefore the numbers for them is not important. It is recommended to use '1' for both as a dummy.
2. Management '1' (mowing) may not be combined with a frequency of '0' and a mowing frequency of '0'. Both values must be higher than '0'. Using '0' for the frequency will give an error message (division by zero) when the Nature Planner is used. The rest of the run will be continued for that cell without SUMO and thus will give a wrong output.
3. Management '2' (turf stripping) may not be combined with a frequency of '0'. Here also a division by zero will take place.
4. Management '7' (turf stripping in combination with mowing once a year) may not be combined with frequency of '0'.
5. Management '8' (road verge management) may not be combined with frequency of '0'.
6. Management '9' (turf stripping in combination with the removal of shrubs and trees) may not be combined with frequency of '0'.
7. Management '10' (fire) may not be combined with frequency of '0'.



*Table 4.2.3. Tree species modelled by SUMO.*

<b>Species</b>	<b>Code</b>
no tree species	GEE
birch	BER
beech	BEU
oak	EIK
northern red oak	AME
ash tree	ES
alder	ELS
willow	WIL
poplar	POP
Douglas	DOU
spruce	FIJ
pine	GRO
larch	LAR
Zilverspar	ZIL
Sitka spar	SIT
Alepedoden	ALE
Zeeden	ZEE
Moseik	MOS
Steeneik	STE
Bergeik	BEG
Kurkeik	KUR
Wintereik	WIN
Zwarte den	ZWA

*Table 4.2.4. Vegetation types modeled (vegtype) in SUMO*

<b>Vegetation type number</b>	<b>Vegetation type</b>
1	grassland
2	heathland
3	dark coniferous forest
4	light deciduous forest
5	light coniferous forest
6	dark oak beech forest
7	dark beech forest
8	structure rich deciduous forest
9	reed
10	shrub
11	salt marshes
12	peat bog
13	swamp
14	no vegetation
15	-
16	Road verge with trees
17	Wooded bank

*Table 4.2.5. Grazers present in SUMO.*

<b>Grazer</b>
Domestic cattle
'Wild' cattle
Young cattle
European bison
Pony
Hors
Sheep
Moose
Roe deer
Red deer
Fallow deer
Moufflon
Wild boar
Goose
Rabbit

*Table 4.2.6. Possible combination of vegetation type, tree species, stand age and file number for SUMO. Where only one tree species is given the other species can be chosen freely from the species pool given in table 4.2.3, the given species is the dominant one, containing the major part of the biomass. The explanation for the vegetation type number is given in table 4.2.4. Tree species not present in the table, but present in table 4.2.4 can be used in stead of a given tree species.*

<b>Vegetation type</b>	<b>File number</b>	<b>Vegetation type number</b>	<b>Initial age (y)</b>	<b>Tree species (climax tree)</b>
dune shrub	1	10	50	GEE, GEE
dune open vegetation	2	2	20	GEE, GEE
salt marsh	3	11	50	GEE, GEE
reed	4	9	10	GEE, GEE
Rough land	5	1	10	GEE, GEE
managed grassland	6	1	10	GEE, GEE
natural grassland	7	1	10	GEE, GEE
heath <75% grass	8	2	10	GEE, GEE
heath >75 % grass	9	2	25	GEE, GEE
peat bog	10	12	50	GEE, GEE
no vegetation	11	2	1	GEE, GEE
natural vegetation	12	1	10	GEE, GEE
swamp	13	13	10	GEE, GEE
northern red oak <40 years	14	4	30	AME
northern red oak 40-80 years	15	4	60	AME
northern red oak 80-120 years	16	4	100	AME
northern red oak >120 years	17	4	130	AME
beech <40 years	18	7	30	BEU
beech 40-80 years	19	7	60	BEU
beech 80-120 years	20	7	100	BEU
beech >120 years	21	7	140	BEU
douglas <40 years	22	3	30	DOU, FIJ
douglas 40-80 years	23	3	60	DOU, FIJ
douglas 80-120 years	24	3	100	DOU, FIJ
douglas >120 years	25	3	130	DOU, FIJ
oak <40 years	26	4	30	EIK
oak 40-80 years	27	4	60	EIK
oak 80-120 years	28	4	100	EIK
oak >120 years	29	4	140	EIK

Vegetation type	File number	Vegetation type number	Initial age (y)	Tree species (climax tree)
alder <40 years	30	4	30	ELS
alder 40-80 years	31	4	60	ELS
alder 80-120 years	32	4	100	ELS
alder >120 years	33	4	130	ELS
scots pine <40 years	34	5	30	GRO
scots pine 40-80 years	35	5	60	GRO
scots pine 80-120 years	36	5	100	GRO
scots pine >120 years	37	5	130	GRO
larch <40 years	38	5	30	LAR
larch 40-80 years	39	5	60	LAR
larch 80-120 years	40	5	100	LAR
larch >120 years	41	5	130	LAR
poplar <40 years	42	4	30	POP
poplar 40-80 years	43	4	60	POP
poplar 80-120 years	44	4	100	POP
wilow <40 years	45	4	30	WIL
wilow 40-80 years	46	4	60	WIL
wilow 80-120 years	47	4	100	WIL
wilow >120 years	48	4	130	WIL
new forest	49	8	20	GEE
timber-felling	50	8	1	Any tree combination
alder coppice	51	8	50	ELS
willow coppice	52	8	50	WIL
oak coppice	53	8	50	EIK
ash tree coppice	54	8	50	ES
Road verge with newly planted trees	55	8	2	Any tree combination
Road verge with trees <40 years	56	8	30	Any tree combination
Road verge with trees 40-80 years	57	8	60	Any tree combination
Road verge with trees 80-120 years	58	8	100	Any tree combination
Road verge with trees >110 years	59	8	110	Any tree combination

### 4.3 Output files of SUMO

SUMO2 gives several files with output. The output can not be defined by the user as for SMART2. For an output deviating from the standard output adjustments to the program code have to be made. Needless to say, that this situation is not ideal and needs improvement.

The most extended output of SUMO2 gives four output files. A global explanation per output file is given in Table 4.3.1. Detailed information for each output column in each output file can be found by using the links in the table. All files are in ascii-format.

Table 4.3.1. Brief description of the output files of SUMO.

File name	Output
<u>Biomassa1.out</u>	Biomass (total, per functional type, per organ and NPP), eaten biomass (Total and per organ), harvested biomass (per organ), height (per functional type), vegetation type, management, nitrogen en phosphorus input and output. For an explanation of the file see Table 4.3.2.
<u>Strooisel.out</u>	Litterfall per organ, with N and P content. For an explanation of the file see Table 4.3.3.
<u>NPverh.out</u>	Reductionfactors of the growth based on the N and P availability per functional type, potential growth per functional type. For an explanation of the file see Table 4.3.4.
<u>NPgehalte.out</u>	N and P content per organ, N/P ratio per organ and for the soil. For an explanation of the file see Table 4.3.5.
<u>N_balans</u>	Mass balance output file for nitrogen
<u>C_balans</u>	Mass balance output file for carbon (biomass). For an explanation of the file see Table 4.3.6.
<u>P_balans</u>	Mass balance output file for phosphorus. For an explanation of the file see Table 4.3.7.

Table 4.3.2. Explanation of the output in the file biomassa1.out.

	Organ	Short	Explanation	Unit
		xcoord	X coordinate	m
		ycoord	Y coordinate	m
		vegtype	Vegetation type	-
		filenr	File number	-
		LARCH	LARCH vegetation type	-
		tree1	Tree species 1 (pioneer tree)	-
		tree2	Tree species 2 (climax tree)	-
		year	Run year	y
biomass	total	herbs	Total biomass herbs at time t	Ton/ha
		dwarfshrubs	Total biomass dwarfshrubs at time t	Ton/ha
		shrubs	Total biomass shrubs at time t	Ton/ha
		tree1	Total biomass tree1 at time t	Ton/ha
		tree2	Total biomass tree2 at time t	Ton/ha
		total	Total biomass at time t	Ton/ha
		eaten	Total eaten biomass at time t	Ton/ha
	roots	herbs	Total biomass roots herbs at time t	Ton/ha
		dwarfshrubs	Total biomass roots dwarfshrubs at time t	Ton/ha
		shrubs	Total biomass roots shrubs at time t	Ton/ha
		Tree1	Total biomass roots tree1 at time t	Ton/ha
		tree2	Total biomass roots tree2 at time t	Ton/ha
	stem	herbs	Total biomass stems herbs at time t	Ton/ha
		dwarfshrubs	Total biomass stems dwarfshrubs at time t	Ton/ha
		shrubs	Total biomass stems shrubs at time t	Ton/ha
		tree1	Total biomass stems tree1 at time t	Ton/ha
		tree2	Total biomass stems tree2 at time t	Ton/ha
	leaf	herbs	Total biomass leaves herbs at time t	Ton/ha
		dwarfshrubs	Total biomass leaves dwarfshrubs at time t	Ton/ha
		shrubs	Total biomass leaves shrubs at time t	Ton/ha
		tree1	Total biomass leaves tree1 at time t	Ton/ha
		tree2	Total biomass leaves tree2 at time t	Ton/ha
	height	herbs	Height herbs at time t	m
		dwarf	Height dwarfshrubs at time t	m

	<b>Organ</b>	<b>Short</b>	<b>Explanation</b>	<b>Unit</b>
		shrubs	Height shrubs at time t	m
		tree1	Height tree1 at time t	m
		tree2	Height tree2 at time t	m
eaten	roots	herbs	Eaten biomass roots herbs at time t	Ton/ha
		dwarf	Eaten biomass roots dwarfshrubs at time t	Ton/ha
		shrubs	Eaten biomass roots shrubs at time t	Ton/ha
		tree1	Eaten biomass roots tree1 at time t	Ton/ha
		tree2	Eaten biomass roots tree2 at time t	Ton/ha
	stem	herbs	Eaten biomass stems herbs at time t	Ton/ha
		dwarf	Eaten biomass stems dwarfshrubs at time t	Ton/ha
		shrubs	Eaten biomass stems shrubs at time t	Ton/ha
		tree1	Eaten biomass stems tree1 at time t	Ton/ha
		tree2	Eaten biomass stems tree2 at time t	Ton/ha
	leaf	herbs	Eaten biomass leaves herbs at time t	Ton/ha
		dwarf	Eaten biomass leaves dwarfshrubs at time t	Ton/ha
		shrubs	Eaten biomass leaves shrubs at time t	Ton/ha
		tree1	Eaten biomass leaves tree1 at time t	Ton/ha
		tree2	Eaten biomass leaves tree2 at time t	Ton/ha
		Navail	Nitrogen availability at time t	Ton/ha
		N back	Nitrogen reallocated at time t	Ton/ha
		Pavail	Phosphorus availability at time t	Ton/ha
		Pback	Phosphorus reallocated at time t	Ton/ha

*Table 4.3.3. Explanation of the output in the file Strooisel.out*

<b>Organ</b>	<b>Short</b>	<b>Explanation</b>	<b>Unit</b>
	<b>year</b>		<b>y</b>
roots	biomass	Biomass of dead roots at time t	Ton/ha
	[N]	Nitrogen content of the dead roots at time t	-
	[P]	Phosphorus content of the dead roots at time t	-
stem	biomass	Biomass of dead stems (litter) at time t	Ton/ha
	[N]	Nitrogen content of the dead stems (litter) at time t	-
	[P]	Phosphorus content of the dead stems (litter) at time t	-
leaves	biomass	Biomass of dead leaves (litter) at time t	Ton/ha
	[N]	Nitrogen content of the dead leaves (litter) at time t	-
	[P]	Phosphorus content of the dead leaves (litter) at time t	-

*Table 4.3.4. Explanation of the output in the file NPverh.out*

	<b>Short</b>	<b>Explanation</b>	<b>Unit</b>
	year		y
	xcoord	X coordinate	m
	ycoord	Y coordinate	m
	Navail	Nitrogen availability at time t	Ton/ha
	Pavail	Phosphorus availability at time t	Ton/ha
Growth reduction factor for N	herbs	Growth reduction for nitrogen for herbs at time t	-
	dwarf	Growth reduction for nitrogen for dwarfshrubs at time t	-
	shrubs	Growth reduction for nitrogen for shrubs at time t	-
	tree1	Growth reduction for nitrogen for tree1 at time t	-
	tree2	Growth reduction for nitrogen for tree2 at time t	-
Growth reduction factor for P	herbs	Growth reduction for Phosphorus for herbs at time t	-
	dwarf	Growth reduction for Phosphorus for dwarfshrubs at time t	-
	shrubs	Growth reduction for Phosphorus for shrubs at time t	-

	<b>Short</b>	<b>Explanation</b>	<b>Unit</b>
actual growth	tree1	Growth reduction for Phosphorus for tree1 at time t	-
	tree2	Growth reduction for Phosphorus for tree2 at time t	-
	herbs	The realised growth for herbs at time t	Ton/ha
	dwarf	The realised growth for dwarfshrubs at time t	Ton/ha
	shrubs	The realised growth for shrubs at time t	Ton/ha
potential growth	tree1	The realised growth for tree1 at time t	Ton/ha
	tree2	The realised growth for tree2 at time t	Ton/ha
	herbs	The potential growth for herbs at time t	Ton/ha
	dwarf	The potential growth for dwarfshrubs at time t	Ton/ha
	shrubs	The potential growth for shrubs at time t	Ton/ha
	tree1	The potential growth for tree1 at time t	Ton/ha
	tree2	The potential growth for tree2 at time t	Ton/ha

*Table 4.3.5. Explanation of the output in the file NPgehalte.out*

	<b>Short</b>	<b>Explanation</b>	<b>Unit</b>	
	year		y	
	xcoord	X coordinate	m	
	ycoord	Y coordinate	m	
Ncontent	roots	herbs	Nitrogen content in the roots of the herbs at time t	-
		dwarf	Nitrogen content in the roots of the dwarfshrubs at time t	-
		shrubs	Nitrogen content in the roots of the shrubs at time t	-
		tree1	Nitrogen content in the roots of the tree1 at time t	-
		tree2	Nitrogen content in the roots of the tree2 at time t	-
	stem	herbs	Nitrogen content in the stems of the herbs at time t	-
		dwarf	Nitrogen content in the stems of the dwarfshrubs at time t	-
		shrubs	Nitrogen content in the stems of the shrubs at time t	-
		tree1	Nitrogen content in the stems of the tree1 at time t	-
		tree2	Nitrogen content in the stems of the tree2 at time t	-
leaves	herbs	Nitrogen content in the leaves of the herbs at time t	-	
	dwarf	Nitrogen content in the leaves of the dwarfshrubs at time t	-	
	shrubs	Nitrogen content in the leaves of the shrubs at time t	-	
	tree1	Nitrogen content in the leaves of the tree1 at time t	-	
	tree2	Nitrogen content in the leaves of the tree2 at time t	-	
Pcontent	roots	herbs	Phosphorus content in the roots of the herbs at time t	-
		dwarf	Phosphorus content in the roots of the dwarfshrubs at time t	-
		shrubs	Phosphorus content in the roots of the shrubs at time t	-
		tree1	Phosphorus content in the roots of the tree1 at time t	-
		tree2	Phosphorus content in the roots of the tree2 at time t	-
	stem	herbs	Phosphorus content in the stems of the herbs at time t	-
		dwarf	Phosphorus content in the stems of the dwarfshrubs at time t	-
		shrubs	Phosphorus content in the stems of the shrubs at time t	-
		tree1	Phosphorus content in the stems of the tree1 at time t	-
		tree2	Phosphorus content in the stems of the tree2 at time t	-
	leaves	herbs	Phosphorus content in the leaves of the herbs at time t	-
		dwarf	Phosphorus content in the leaves of the dwarfshrubs at time t	-
		shrubs	Phosphorus content in the leaves of the shrubs at time t	-
		tree1	Phosphorus content in the leaves of the tree1 at time t	-
		tree2	Phosphorus content in the leaves of the tree2 at time t	-

Table 4.3.6. Explanation of the output in the file *N\_balans.out*

Short	Explanation	Unit
xcoord	X coordinate	m
ycoord	Y coordinate	m
jaar	year	y
Nbesch	Nitrogen availability at time t	Ton/ha
opnameNtot	Total amount of nitrogen taken up by the vegetation at time t	Ton/ha
Nterug_bodem_tot	Total amount of nitrogen that is not taken up by the vegetation at time t	Ton/ha
Nterug	Total amount of nitrogen reallocated by the vegetation at time t	Ton/ha
bladopname	Total amount of nitrogen adsorbed directly by leaves at time t	Ton/ha
bemesting	Manuring at time t	Ton/ha
Nfix	Nitrogen fixation by the vegetation at time t	Ton/ha
Nout	Nitrogen removed from the system at time t (by management)	Ton/ha
Norg_tot	Total amount of nitrogen present in the vegetation at time t	Ton/ha
Nlitter	Total amount of nitrogen present in the litter (dead roots, dead wood and dead leaves) at time t	Ton/ha
zaadN_tot	Total amount of nitrogen in the seed input at time t	Ton/ha

Table 4.3.7. Explanation of the output in the file *C\_balans.out*

Short	Explanation	Unit
xcoord	X coordinate	M
ycoord	Y coordinate	M
jaar	year	Y
biomtott	Total biomass at year t (over all organs and functional types)	Ton/ha
gegetentot	Total amount of biomass eaten by all grazers at time t	Ton/ha
afvoerbomt	Total amount of biomass removed from the system at time t (by management)	Ton/ha
dblادت	Total amount of dead leaves at time t	Ton/ha
dworteltot	Total amount of dead roots at time t	Ton/ha
doodhouttot	Total amount of dead wood at time t	Ton/ha
biom	Amount of biomass per organ and functional type at time t. In total 15 columns, biomasses are given in the sequence herbs, dwarfshrubs, shrubs, tree1 and tree2 combined with roots, stems and leaves (as described in the tables above)	Ton/ha
grtot	Total growth over all organs and functional types at time t	Ton/ha
zaadtot	Total amount of seed input at time t	Ton/ha

Table 4.3.8. Explanation of the output in the file *P\_balans.out*. The output files for the *Ca*, *Mg* and *K* balans are exactly the same as for *P*.

Short	Explanation	Unit
xcoord	X coordinate	M
ycoord	Y coordinate	M
jaar	year	Y
Pbesch	Phosphorus availability at time t	Ton/ha
opnamePtot	Total amount of Phosphorus taken up by the vegetation at time t	Ton/ha
Pterug_bodem_tot	Total amount of Phosphorus that is not taken up by the vegetation at time t	Ton/ha
bemestingP	Manuring at time t	Ton/ha
Pout	Phosphorus removed from the system at time t (by management)	Ton/ha
Porg_tot	Total amount of Phosphorus present in the vegetation at time t	Ton/ha
Plitter	Total amount of Phosphorus present in the litter (dead roots, dead wood and dead leaves) at time t	Ton/ha
zaadPtot	Total amount of Phosphorus in the seed input at time t	Ton/ha

#### **4.4 Description of the standard test set for SMART (sms\_nl\_nt) v3.0 and SUMO2 v3.2.1**

For the technical testing of SMART-SUMO a standardized test set is available. This set contains a wide variation of input, in which the most important combinations of input are present, but not all possible combinations, though every single input variable is present for all possible values, i.e. for the input variable management ('beheer1') all 10 possible options are present in the test set. The test set will be extended for every new feature added to SMART2 or SUMO2. Therefore the test set is specific for every version of SMART2 SUMO2. By varying the input for the three site specific inputfiles (grid\_s\_v\_dat, vegout\_2\_3.txt and extra\_manag\_2\_3.txt) not only the input variables containing these files are varied but also the site specific input that depends on the coordinates given in the files, i.e. deposition and rain amount, but also soil and vegetation dependent input and model parameters.

The full extent of the test set for SMART2 v\* and SUMO2 v3.2.1 is given in standard SMART input for the file grid\_s\_v\_2\_3.dat (input for SMART2), in standard input SUMO for the file vegout\_2\_3.txt (standard input for SUMO) and extra management for the file extra\_manag\_2\_3.txt (input for SUMO).

When SUMO2 is changed without the implementation of new conceptual features the outcome of the testset has to be exact the same as before the implementation. Also because of this the testset is a part of the version management system. When new conceptual features are implemented then the model has to be revalidated using the datasets described before (see Wamelink 2007 and de Vries *et al.* 2007). After parameterization a new standard result of the testset will be used to control future changes.

Almost all possible combinations of vegetation types and management combinations are tested at least for one site. Also it is controlled if the same input results in the same output. This is combined with different soil types and groundwater tables as input for SMART2. The model is also controlled using forcheck (Wamelink *et al.* 2008).



## 5 Model Applications in projects

SUMO as an integrated model in SMART2 is used in several projects. For each of these projects a short summary is given. SMART2-SUMO2 is also the core of the Natureplanner and as such also used in many projects involving the Natureplanner. The results of the model runs with the Natureplanner are not summarised here, neither are the reports that only describe model development.

### ***Validation of SMART2, SUMO 1, NUCOM and MOVE 2***

The Models SMART2, SUMO 1, MOVE2 and NUCOM were validated on site regional and national scale (Wamelink *et al.* 2001a). The results from NUCOM were compared with the results from the other three models. On the site level the predictions of the models turned out to be adequate. The model NUCOM predicted the biomasses for the sites somewhat better than SUMO for Hulshorsterzand. For the Sellingen site biomass predictions were comparable for both models. On a regional scale (Veluwe) the pH values in the soil were modelled adequate as well, both by NUCOM and by SMART. The nitrogen availability could only be compared between the two models. SMART simulated a smaller range in nitrogen availability than NUCOM. NUCOM predicted higher nitrogen availabilities for unmanaged forest, heathland and grassland. The predictions made by MOVE about the occurrence of plant species showed a significant positive relation with the occurrence of plant species in the field. However the explained variance was very low, indicating that the predictions of the plant species are poor. Only SMART-SUMO was tested on a national scale. The simulated pH showed a satisfying relation with field pH.

### ***Consequences of the establishment of a pig farm for the surrounding nature***

The effects of the establishment of a pig farm near a natural area were investigated (van Dobben *et al.* 2002). The natural area was classified as a habitat directive area. The effects of the extra emission by the farm on the natural area were simulated using the models SMART2-SUMO-NTM3. The effects of the farm were not significant. However the effects of the background deposition proved to be very serious. Therefore it remained unclear whether or not the farm could be allowed. Since the habitat directive says that when nature is threatened then no extra pressure is allowed on the natural area. Though not significant, the farm would contribute to the pressure.

### ***Use of coupled models to predict biodiversity in managed ecosystems***

A model chain was used to estimate the feasibility of biodiversity targets for two ecosystem types at three environmental scenarios (van Dobben *et al.* 2002, Wamelink *et al.* 2002, van Dobben *et al.* 2003). The ecosystems studied were pine forest and heathland on oligotrophic dry sandy soil. The scenarios comprised a constant (45 kg ha<sup>-1</sup> y<sup>-1</sup> N) and decreasing (from 45 kg ha<sup>-1</sup> y<sup>-1</sup> N in 1990 to 10 kg ha<sup>-1</sup> y<sup>-1</sup> N in 2090) deposition of nitrogen, and a proportional decrease of acid deposition. Management was assumed to be 'natural' forest management (i.e., removal of 10% of the stem wood each 10 years) and sod-cutting (once each 30 years) in the heathland, combined with grazing in one of the scenarios. The models used were: SMART2 (soil chemistry), SUMO2 (plant growth and competition) and NTM3 / NTM4 (vegetation composition and biodiversity). The models were initialised using field observations from the period 1990 - 2000. Simulation runs were made for the period 1990 - 2090. Results showed that (a) the effect of decreasing nitrogen deposition is limited in the forest because excess nitrogen is only very slowly removed from the ecosystem, and (b) grazing enhances the beneficial effects of decreasing deposition.

### ***The estimation of the initial biomass for SUMO using remote sensing***

Data gathered using remote sensing (NDVI) was used to estimate the amount of biomass at several natural sites (Hazeu *et al.* 2002, Hazeu & Wamelink 2004). The biomass was used as input for the model SUMO. The simulated biomass was compared with independent biomass estimates with remote sensing. The results were inconclusive though some methods of estimating the biomass from NDVI showed promising results.

### ***Decreasing deposition will reduce costs for nature management***

In two projects the costs of nature management due to deposition were estimated using SUMO. The abstracts of the two projects are given below.

Effects of atmospheric deposition on natural areas can be mitigated by management (Wamelink *et al.* 2003d Wamelink *et al.* 2005). For example, the effects of excessive nitrogen deposition can partly be overcome by intensifying measures like mowing or sod-cutting. The costs of this extra management may in future no longer be required when deposition rates decrease. We developed a method to calculate the costs of the intensified nature management that is required at increased deposition rates. We used a set of models that simulate the biomass development under different management regimes necessary to maintain a certain level of biodiversity. The costs were calculated for several vegetation types, based on, amongst others, the biomass and litter that was removed. Preliminary results show that the models can be applied with some success to assess these costs. Model outcomes show a clear effect of management intensity on biomass growth in heathland and grassland, though no differences were found in forest. The biodiversity in heathlands clearly increased when management was intensified. As an example the extra costs in heathlands that are made to counteract the effects of atmospheric deposition were calculated for The Netherlands. The costs of maintaining heathlands with sods being removed from heathlands every 20 years (presently the usual rate), exceed those in a situation of sod cutting every 60 years (the expected rate without atmospheric deposition) by 1.4 m Euro per year.

An estimation of the additional costs made by nature reserve managers to mitigate the effects of atmospheric deposition is made (de Jong *et al.* 2004, Wamelink *et al.*). The costs are estimated on a national scale, in this case for The Netherlands. The costs of increasing deposition levels – or the benefits of reducing deposition levels – were calculated from the costs for nature management per Nature Target Type (NTT) and management intensity for both the current (high) and reduced deposition levels, which result in a similar ecological quality. For the NTTs within the clusters grassland, reed and rough land, and heathland model simulations were run using vegetation simulation models. For forests and moorland pools we used expert knowledge to estimate the reduction in management costs due to a decrease in deposition. The total amount of money that may be saved because of the reduction of deposition rates is estimated on 42 million euro per year for the period from 2000 till 2020 for the assessed NTTs. The highest savings can be made in grasslands; 28 million euro.

### ***Effect of a hedge on the emission of ammonia from a pig farm***

In this research SUMO was used to estimate the height and biomass growth of a hedge near a pig farm (van Dijk *et al.* 2005). The interception and resulting deposition of ammonia by the hedge was estimated from field measurements. The effect of the pig farm was compared with the background deposition of the site (i.e. the natural deposition and the deposition of all other sources, but exclusive the deposition from the pig farm). It showed that the farm had a significant effect on the vegetation structure. The tree biomass and grasses biomass was much higher due to the emissions from the pig farm.

### ***The effectiveness of nature management of grasslands; a model simulation***

The effects of various types of nature management on the botanic quality of low-lying grasslands (situated below sea level on peatlands) in the Netherlands can vary tremendously (Wamelink & van Dobben 2004). Management measures are necessary to maintain existing biodiversity and restore lost biodiversity in these grasslands. The agreed goals can be achieved by various methods, at different costs. The aim of the present study was to investigate which management type could meet the biodiversity goals at the lowest cost. This was modelled using the 'Nature Planner', a set of soil and vegetation simulating models. We ran 24 different management scenarios, including combinations of mowing, grazing, groundwater management, fertilization and removal of the top layer on former agricultural grasslands. The probability of occurrence of two grassland types, 'flower-rich grassland' and 'wet nutrient-poor grassland' was simulated for 20 sites in the west and the north of the Netherlands.

As expected, management has a major influence on the biomass development and vegetation succession in the grasslands. Mowing greatly increases the probability of occurrence of the selected vegetation types, as does the combination of mowing and grazing, while grazing favours wet nutrient-poor grassland. Grazing alone has a negative influence on the probability of occurrence of flower-rich grassland. The probability of occurrence on former agricultural land is small for both types, even after removal of the topsoil. This is a surprising finding, since topsoil removal was expected to increase the probability of these two vegetation types. This result is probably caused by a flaw in the models. We also expected a low-intensity fertilization regime to have an unfavourable effect on the probability of occurrence. Whereas this was indeed found to be the case for wet nutrient-poor grassland, fertilization at up to 50 kg N/ha still yielded a high probability of occurrence of flower-rich grasslands. This may indicate that this type could flourish under agri-environmental schemes. Before implementing this, it should be tested in the field. The influence of groundwater management was found to be minimal, but this was probably also due to incomplete simulation by the models. Improvements to the models are soon to be implemented.

Of all the management types, grazing is the cheapest and mowing the most expensive. Grazing alone, however, is not sufficient to maintain the grassland status; in the end, succession to forest will occur. Therefore, although expensive, mowing, whether or not in combination with grazing, is the only option to maintain the grassland status. Adding grazing would have some additional benefits and makes the management cheaper.

The variation between the sites was sometimes large, indicating that the choice of management to achieve the agreed goals must be defined for each site.

### ***Chances for nature in the Dutch lowland grasslands. A costs analyses and modelsimulation.***

In the 20th century many lowland grassland, mostly situated on peat, have suffered from lowering of the groundwater level and intensified agricultural use. In the coming years for approximately 5000 ha of grassland the groundwater levels will be raised again in an effort to regain the nature values these grasslands once possessed. To be able to estimate the effects of several scenario's of management in combination with deposition scenario's on the nature value we applied the models SMART2-SUMO2 and BIODIV, all part of the decision support system the 'Natuurplanner'.

In total we evaluated 115 combinations of mowing, grazing, change in groundwater level, manuring and change in deposition rate. When farmland is taken out of agricultural use by farmers, this will reduce the income of the farmer due to extra costs and less harvest of grass. To compensate farmers the Dutch government pays the farmers for this loss in

income. We made a first attempt to estimate the actual loss of income for the farmer and compared it with the compensation. All results are simulated and calculated for two regions in the Netherlands, one in the north and one in the west, based on many individual sites.

The highest chances for nature occur in the north and it seems wise to plan the more vulnerable nature types there. The optimal management consists of the combination of mowing and grazing for a decreasing nitrogen deposition. Moreover extra costs for the farmer are relatively low. In combination with lower deposition rates extensively manuring in combination with mowing and grazing gives also fairly high chances for nature and gives the lowest extra costs. The raise of the groundwater level will also give higher chances, but also brings higher costs.

The use of manure on the more natural grasslands is very restricted and only for a part of the vegetation types allowed in an extensive way. The extra costs for the farmer largely depend on the possibility to use the manure on the rest of his agricultural land. When this is possible the compensation paid by the government may be enough to compensate for the loss in income. For some more difficult to realize nature target types the compensation is far too low. When the farmer can not use the manure on his own land, it has to be transported sometimes even to other regions. This brings enormous costs which are by far not compensated by the subsidies from the government.

#### ***Atmospheric nitrogen pollution impacts on biodiversity: Phase 1 – Model development and testing***

The emphasis in this project was primarily on the impacts of N deposition but in order to develop a capacity for testing realistic scenarios of past and future ecological change we sought to develop linked models and filters sensitive to other key drivers that could constrain or exacerbate the effects of atmospheric nitrogen. Hence, modelling biomass accumulation was based on testing and modifying the Dutch SUMO model. Two separate trait-based filters were also developed. In order to model management impacts on the vegetation, the Dutch soil and succession models SMART/SUMO were tested on a number of UK sites and various modifications made to adapt the SUMO model to British conditions. Testing and validation produced promising results, for example the time series of biomass production in the Rothamsted Park Grass control plots was very well reproduced. Further testing is highly desirable yet limited by available data.

#### ***Modelling impacts of changes in CO<sub>2</sub> concentration, climate change and nitrogen deposition on carbon sequestration of European Forest***

Changes in the Earth's atmosphere are expected to influence the growth and therefore carbon accumulation of European forests. We identify three major changes: (1) a raise in carbon dioxide concentration, (2) climate change, resulting in higher temperatures and changes in precipitation and (3) a decrease in nitrogen deposition. We adjusted and applied the hydrological model Watbal, the soil model SMART2 and the vegetation model SUMO2 to assess the effect of expected changes in the period 1990 up to 2070 on the carbon accumulation in trees and soils of 166 European forest plots. The models were parameterized using measured soil and vegetation parameters and site-specific changes in temperature, precipitation and nitrogen deposition. The carbon dioxide concentration was assumed to rise uniformly across Europe. The results were compared to a reference scenario consisting of a constant CO<sub>2</sub> concentration and deposition scenario. The temperature and precipitation scenario were a repeatment of the period between 1960 and 1990. All scenarios were compared to the reference scenario for biomass growth and carbon sequestration for both the soil and trees.

The predicted effects of changes in climate, CO<sub>2</sub> concentration and nitrogen deposition on carbon sequestration by trees depend largely on tree species and location (latitude). The assumed decrease in nitrogen deposition causes a decrease of carbon accumulation all over Europe and for all modelled tree species. A raise in carbon dioxide concentration gives a raise in carbon accumulation all over Europe. Climate change gives a mixed result, with a decrease in carbon accumulation in the South of Europe and an increase in the North. When the scenarios are combined, an increase in biomass accumulation is predicted at most of the sites, with a raise in growth rate mostly between 0% and 100%. The predicted effects of a change in climate, CO<sub>2</sub> concentration and nitrogen deposition depends on soil carbon sequestration is generally lower than on carbon sequestration by the trees but the magnitude is similar and also the dependence on location (latitude). A net carbon release was predicted at several sites in the south due to the effect of climate change. Overall, we conclude that where nitrogen deposition was a major driver for a change in forest growth in the past, it is climate change and to a lesser extent CO<sub>2</sub> change that will influence forest growth in the future.

***Effect of nitrogen deposition reduction on biodiversity and carbon sequestration***

Global warming and loss of biodiversity are among the most prominent environmental issues of our time. Large sums are spent to reduce their causes, the emission of CO<sub>2</sub> and nitrogen compounds. However, the results of such measures are potentially conflicting, as the reduction of nitrogen deposition may hamper carbon sequestration and thus increase global warming. Moreover, it is uncertain whether a lower nitrogen deposition will lead to a higher biodiversity. In this study we forecast that a gradual decrease in nitrogen deposition from 40 to 10 kg N ha<sup>-1</sup>·y<sup>-1</sup> in the next 25 years will cause a drop in the net carbon sequestration of forest in The Netherlands to 27% of the present amount, while biodiversity remains constant in forest, but may increase in heathland and grassland.



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