REPORT SNO 3696-97

MERLIN model applied to NITREX Gårdsjön

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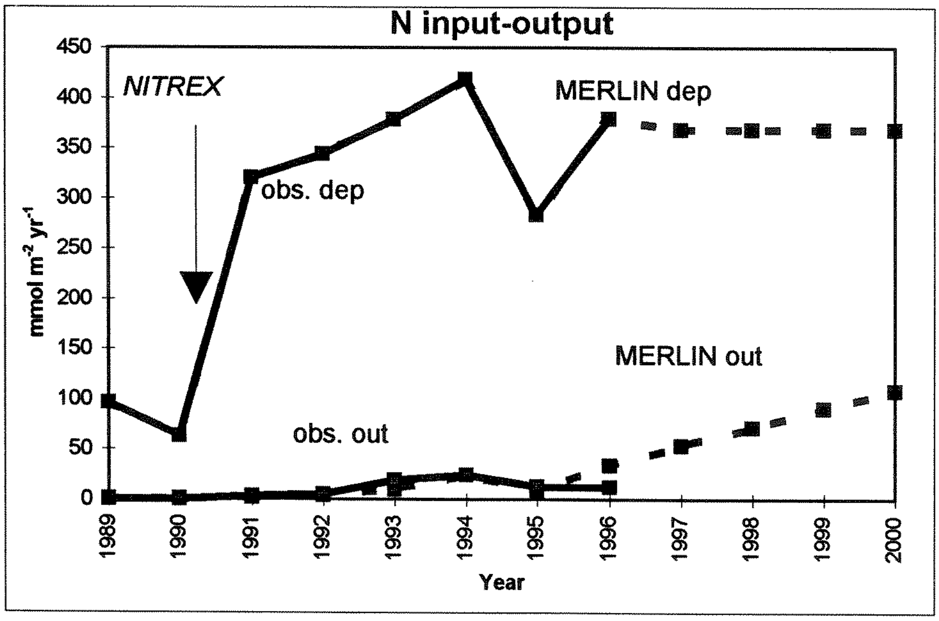
REPORT 46/97



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REPORT

Title MERLIN model applied to NITREX Gårdsjön	Serial No. 3696-97	Date 27 june 1997
	Report No. Sub-No. O-95038	Pages Price 38
Author(s) *Kjønaas, O. Janne (NISK)* Wright, Richard F. *Cosby, B.J. (University of Virginia)*	Topic group acid precipitation	Distribution
	Geographical area Sweden	Printed NIVA

Client(s) Research Council of Norway (NFR) (TVLF)	Client ref. 108044/720

Abstract

A new process-oriented dynamic model, MERLIN, has been tested on a nitrogen-manipulated catchment at Gårdsjön, Sweden, to elucidate the time aspects of nitrogen "saturation". The model is calibrated to the period 1930-90 and the first 4 years of N addition (1991-94), and then compared with data for the 5th and 6th years. The calibrated model is used to predict future trends in N leaching. The model indicates that most of the added N goes to forest floor soil and very little to the plants. This agrees with measured N concentrations in needles. The model calibrated well to the flux of N out of the catchment during the first 4 treatment years, and correctly predicted the 5th year but overestimated the 6th year. In the model, significant leaching occurs as the optimum C/N ratio in forest floor is reduced from the 1990 value of about 35 to about 25. This agrees with the general results from the European NITREX sites, at which significant N leaching occurs at sites with low C/N ratio in the forest floor. The time needed for a system to change from N-limited, indicated by a high C/N, to a N-rich system, with C/N ratio below 25 and increased N leaching, is, however, uncertain, and the processes that govern such a transition are not fully understood. A sensitivity analysis is needed, along with further testing on a variety of forest ecosystems evaluate the utility of the model.

4 keywords, Norwegian	4 keywords, English
1. sur nedbør	1. acid precipitation
2. nitrogen	2. nitrogen
3. modell	3. model
4. skog	4. forest

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ISBN 82-577-3261-3

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Preface

This project came about as a result of interest in testing the new MERLIN model with data from NITREX field experiments. The project was supported in 1995 by the NFR Committee “TVLF” (Transport and effects of long-range transported air pollutants). The first application to a NITREX site was Aber, and similar applications of MERLIN to other NITREX sites are in progress, in part with support from the U.S. Department of Energy through contract DE-FG02-92ER30196 with E & S Environmental Chemistry, Inc.

Oslo, May 1997

Richard F. Wright

Contents

1. Summary

Chronic deposition of inorganic nitrogen compounds from the atmosphere to forested ecosystems can lead to changes in ecosystem structure and function. As a result, a forest can move from nitrogen-limited towards a status of nitrogen "saturation", characterised by, among other things, increased leaching of inorganic nitrogen below the rooting zone. To provide information on the time aspects of nitrogen "saturation", a new process-oriented dynamic model, MERLIN, has been tested on a nitrogen manipulated catchment in Gårdsjön, Sweden. The catchment is dominated by naturally generated Norway spruce with Scots pine in drier areas, and the mean age of the forest is 104 years. Since 1991, weekly sprinkling of ammonium nitrate solution at a rate of about 35 kg N ha^{-1} yr^{-1} has been performed to simulate increased atmospheric deposition of nitrogen.

MERLIN (Model of Ecosystem Retention and Loss of Inorganic Nitrogen) describes C and N cycles, and is comprised of 2 plant and 2 soil compartments (labile (LOM) and refractory (ROM) organic matter).Transfers between compartments occurs by means of processes such as plant uptake, litter production, immobilisation, mineralisation, nitrification and denitrification. Rates of plant uptake and cycling between pools are governed by the C/N ratios of the plant and soil pools.

The model is calibrated through a selected hindcast period and then used to predict future trends. For this model application, the year 1930 was chosen as starting point. At this time N deposition was much lower than present-day and the forest was well-established. A major source of uncertainty in model calibration and prediction is the paucity of good historical information on the specific site and stand history over the hindcast period 1930 to 1990. The reconstructed N cycle for the year 1930 reflects the assumption that the forest is slowly aggrading but is otherwise in a steady-state. The small amounts of N required for wood production and loss of DON in runoff come from a small background deposition of N and “mining” of ROM. Because very little happens with N cycling and fluxes in the forest ecosystem during the hindcast period, the model is poorly constrained. The final calibration therefore made use of the results from the first 4 years of N additions, and was then evaluated with the results from the 5th and 6th years.

The calibrated model indicates that most of the added N goes to LOM and very little goes to the plants. This agrees with measured N concentrations in needles, and other independent measurements including N experiments at other NITREX sites and elsewhere. MERLIN simulated net mineralisation somewhat higher than measured *in situ* for the year 1990, while the predicted net mineralisation for 1995 was lower than corresponding *in situ* measured values. The model calibrated well to the data for flux of N out of the catchment during the first 4 treatment years 1991-94, and correctly predicted the 5th year, but overestimated the 6th year. In the model, significant leaching occurs as the optimum C/N ratio in LOM is reduced from the 1990 value of about 35 to about 25. This agrees with the general results from the European NITREX sites, at which significant N leaching occurs at sites with low C/N ratio in the forest floor. The time needed for a system to change from N-limited, indicated by a high C/N of LOM, to a N-rich system, with C/N ratio below 25 and increased N leaching, is, however, uncertain, and the processes that govern such a transition are not fully understood. Thus, the ability of the model to predict N saturation in Scandinavian coniferous forests with high C/N ratios is still uncertain. MERLIN is an important contribution to further development of qualitative understanding of the N cycle in forests. A sensitivity analysis is needed, along with further testing on a variety of forest ecosystems evaluate the utility of the model. Addtional years of data from Gårdsjön will also greatly aid evaluation of the model.

2. Introduction

Chronic deposition of inorganic nitrogen compounds from the atmosphere to forested ecosystems can lead to changes in ecosystem structure and function and to increased loss of inorganic nitrogen to runoff. Alterations in nitrogen cycling can move the ecosystem from nitrogen-limited towards a status of nitrogen "saturation", in which the availability of ammonium and nitrate is in excess of the total combined plant and microbial nutritional demand (Aber et al. 1989). In addition to changes in critical ecosystem processes which may result in low ratio of gross NO_3 and NH_4 immobilisation to gross mineralisation, low soil C/N ratio, high foliar N concentration and high foliar N/lignin ratio, nitrogen "saturation" is often manifest by high leaching of inorganic nitrogen below the rooting zone both during snow melt and during base flow (Aber, 1992) and increased concentrations of nitrate in surface waters (Stoddard 1994).

Prediction of the amount and number of years of nitrogen deposition a given forest ecosystem can tolerate before nitrogen "saturation" occurs is essential for the determination of critical loads for nitrogen for both forests and surface waters. Models are commonly used to estimate such predications. Empirical models are the simplest. For example, relationships between inputs and outputs of nitrogen to forest ecosystems indicate that forests receiving > 25 kg N ha^{-1} yr^{-1} have significant nitrogen outputs, outputs vary for forests receiving inputs 10-25 kg N ha^{-1} yr^{-1}, and outputs are low when inputs < 10 kg N ha^{-1} yr^{-1} (Dise and Wright 1995). But such an empirical relationship does not indicate the time required for an ecosystem to move from a N-limited to a N-saturated state under a given rate of N deposition.

More detailed models such as process-oriented dynamic models are required to provide information on the time aspects of nitrogen saturation. MERLIN (**M**odel of **E**cosystem **R**etention and **L**oss of **I**norganic **N**itrogen) (Cosby *et al.* 1997) is such a model. MERLIN describes C and N cycles and is comprised of 2 plant and 2 soil compartments (labile and refractory organic matter -- LOM and ROM). Transfer between compartments in the model occurs by means of processes such as plant uptake, litter production, immobilisation, mineralisation, nitrification and denitrification. Rates of plant uptake and cycling between soil pools are assumed governed by the C/N ratios of the plant and soil pools (Cosby *et al.* 1997).

Large-scale, whole ecosystem experiments provide key information for development and testing of predictive models. The NITREX project (Nitrogen saturation experiments) offers such data. NITREX is comprised of 11 experiments at 7 sites in Europe at which nitrogen deposition is experimentally changed to whole ecosystems and the response of vegetation, soils and waters investigated (Wright and van Breemen 1995). One of the NITREX sites is located at Gårdsjön, near Gothenburg, Sweden, at which ambient N deposition of 12 kg N ha^{-1} yr^{-1} is increased to about 50 kg N ha^{-1} yr^{-1} by weekly additions of NH_4NO_3 (Wright et al. 1995). Intensive investigation of vegetation (Kjønaas et al. in press), soil N processes (Kjønaas et al. in press), soil solution (Stuanes and Kjønaas in press) and runoff (Moldan and Wright in press) during the 2 years prior to and 6 years of treatment provide a comprehensive data set for the application of MERLIN.

Here we describe the calibration of MERLIN to NITREX-Gårdsjön data, and evaluate the potential of the model to predict nitrogen saturation in Scandinavian coniferous forests.

3. Site description, methods and data sources

3.1 Site description

The experimental site at Gårdsjön is located at 135-145 m elevation about 10 km from the Swedish west coast (58 04'N, 12 01'E), 50 km north of Gothenburg. The Gårdsjön region has a humid climate, with 1100 mm mean annual precipitation, 586 mm mean annual runoff, and mean annual temperature of 6.4°C. The area is characterised by an acid lake whose terrestrial catchment is dominated by shallow podsolic soils with inclusions of barren rock and peaty soils. The bedrock consists mainly of granites and granodiorites (Olsson et al. 1985).

The G2 NITREX catchment has an area of 0.52 ha. The forest is mainly a naturally-regenerated, uneven-aged Norway spruce (*Picea abies* L. Karst) and some Scotch pine (*Pinus sylvestris* L.) mainly in dry areas. The mean age was 104 years at breast height in 1991. Ground vegetation is dominated by grasses (*Deschampsia flexuosa* (L.) Tin) and mosses (*Dicranum majus* Sm., *Leucobryum glaucum* (Hedw.) Fries) in the upper catchment, (*Vaccinium myrtillus* L./*Vaccinium vitis-idea* L.) in drier outcrops, mosses (*Sphagnum,* predominantly *Sphagnum girgensohnii* Russ.) in the wetter lower parts, and heather (*Calluna vulgaris* (L.) Hill) among the most exposed ridges (Stuanes et al. 1992, Nygaard et al., 1993).

Soils are predominantly acidic silty and sandy loams, drier in the upper catchment and more peaty in the lower parts. They are classified as Orthic Humic Podzols, Orthic Ferro-Humic Podzols, Gleyed Humo-Ferric Podzols, and, at the shallow outcrops, Typic Folisols (The Canadian system of soil classification, 1978). The C/N ratio ranges between 32-52 in the organic horizon. Soil depth ranges from 0 cm to more than 100 cm with an average of 38 cm (Kjønaas et al. 1992, Stuanes et al. 1992).

The Gårdsjön area receives moderately high deposition of sulphate, nitrate and ammonium; 14-year mean (minimum and maximum) throughfall inputs at the nearby F1 CONTROL catchment for 1979 - 1992 were 25.0 (18.9 to 31.6) kg SO_4-S ha^{-1} yr^{-1}, 7.3 (4.6 to 11.7) kg NO_3-N ha^{-1} yr^{-1} and 4.8 (2.4 to 7.7) kg NH_4-N ha^{-1} yr^{-1}, respectively.

3.2 Experimental design

Increased atmospheric deposition of nitrogen is simulated by weekly experimental additions of ammonium nitrate solution at a rate of about 35 kg N ha^{-1} yr^{-1}. NH_4NO_3 is dissolved in de-ionised water and applied by means of 270 ground-level sprinklers installed in a 5x5 m grid over the whole catchment. Additions are done weekly in amounts proportional to the volume of ambient throughfall which occurred the previous week. The additional water comprises about 5% of total throughfall volume. The average ammonium nitrate addition is in 1.4 mm of water and added during 30 minutes. This amount and intensity was chosen such that hydrologic discharge is not affected on an event or an annual basis.

3.3 Methods and data for the forest G2 NITREX 1990 and 1930

The year 1930 was chosen as starting point for this model application. At this time N deposition was much lower than present-day and the forest was well-established.

Values for C and N pools and fluxes for the reference year 1990 were obtained from input-output measurements reported by Moldan et al. (1995), and measurements of tree biomass, litterfall, soil N transformation and soil chemistry reported by Kjønaas et al. (in press).

3.3.1 Pools 1990

Trees:

The total standing biomass was determined using Marklund's biomass functions for pine and spruce separately (Marklund, 1988), with diameter at breast height (dbh) and height of the trees, height to the lowest green branch and site index as input parameters (Kjønaas et al., in press). The various components were divided into a structural "bole" component and an active "crown" component. The active component was calculated as the sum of needles, twigs (1/3 of total branch estimates), and fine roots less than 5 mm. The calculated fine root (< 5 mm) is 3 times the fine root (< 1 mm) biomass reported by Clemmensson-Lindell and Persson (1995). The structural component was calculated as total biomass minus the active component. Total biomass of 1990 was estimated at 155 ton ha^{-1}; 131 and 24 for the active "crown" and structural "bole" pools, respectively. Assuming 50% C in biomass, the C and N pools were 98.6 and 1.58 mol m^{-2} , respectively, for the active pool and 546 and 1.63 mol m^{-2} , respectively, for the structural pool. To estimate tree increment, height and dbh of all trees were measured in 1990 and re-measured in 1994. Foliage was collected once a year in the autumn from the 7th whorl from the top of the tree. The needles from each branch were sorted by age and analysed for total N. Six spruce trees from each of the three vegetation and soil types in G2 were sampled together with six pine trees. There are as yet no data available for estimation of biomass of the ground vegetation; in any case it is small relative to tree biomass, and has been ignored.

Soil:

Soil organic matter consists of material with decomposition times ranging from days to thousands of years. The MERLIN model simplifies the soil organic matter into 2 fractions: a fraction with relatively rapid turnover time (0-10 years) termed "labile organic matter" and a fraction with longer turnover time (10-100 years) "refractory organic matter". Although these types of organic matter are dispersed throughout the soil both vertically and horizontally, in general litter and forest floor consists of more-rapidly decomposed material, whereas organic matter in deep soil layers consists of older material with slower turnover times. For this model run, all the soil organic matter in the forest floor is taken as labile organic matter (LOM), and the organic matter in the mineral horizon is taken as refractory organic matter (ROM). The presence of a smaller horizon of humified organic matter in the forest floor (LOM) and some fine root litter in the mineral horizon (ROM) has thus been ignored. The major fine root distribution is found in the forest floor. The pool of LOM was based on a mean depth of 10.6 cm, a density of 0.1 kg dm^{-3}, 89.7% loss on ignition and 1064 mmol N kg^{-1} soil. The pool of ROM was calculated using a mean depth of 27.4 cm, a density of 1.12 kg dm^{-3}, 4% loss on ignition and 126 mmol N kg^{-1} soil (Kjønaas et al., 1992). This gave C/N ratios for the LOM and ROM pools of 35 and 32, respectively.

3.3.2 Fluxes 1990

Input-output:

Atmospheric inputs are measured by two bulk precipitation collectors and 28 throughfall collectors. Samples for chemical analysis are collected biweekly or monthly and bulked to one sample. Runoff from the G2 NITREX catchment is gauged continuously. Water samples for chemical analysis are collected weekly or biweekly as flow-proportional samples (grab samples prior to November 1991).

The mean deposition for pre-treatment years 1989-90 of nitrogen was 84 mmol N m^{-2} yr^{-1} (sum of wet precipitation and dry deposition). The output in runoff of inorganic nitrogen from the catchment was zero, while the loss of organic nitrogen was 11 mmol m^{-2} yr^{-1} (Moldan et al., 1995).

Litterfall:

Litter is sampled monthly from 23 collectors arranged in five rows near the throughfall samplers. Samples are bulked according to vegetation and soil moisture regime, dried, weighed and sorted (spruce needles, pine needles, cones and "rest"). The samples are analysed quarterly.

Litter flux was taken as the sum of mean total above-ground litterfall for 1990 and 1991 (11.7 mol C m^{-2} yr^{-1}; 187 mmol N m^{-2} yr^{-1}) (Kjønaas et al., in press) and a fine root biomass down to 30 cm depth of 220 g m^{-2} (Clemmensson-Lindell and Persson, 1995). Assuming a below-ground yearly litter production equal to the fine-root biomass, this gives a total carbon litter flux of 22.8 mol m^{-2} yr^{-1}.

Soil nitrogen transformation processes:
A soil-core incubation technique is used to measure the rate and amount of microbiological conversion of organic-N to ammonium (ammonification) and ammonium to nitrate (nitrification). Net N mineralisation is the sum of net ammonification and net nitrification. Rates are compared between 3 plots under different ground vegetation and moisture regimes. The incubations are made *in situ* with ion-exchange resin bags placed at the bottom of soil cores (DiStefano and Gholz, 1986; Kjønaas and Svensson, in prep.). Resin bags are also placed on the surface adjacent to the cores to estimate the relative contribution of incoming nitrogen. Soil cores are collected before each mineralisation study to measure pre-incubation levels of NH_4 and NO_3. Ten replicates are used at each plot. Incubations are conducted over 2-month intervals during the growing season (May-June, July-August, September-October) and over 6 months during the winter (November-April). Denitrification rates have been measured by Klemedtsson et al. (in press) using a closed chamber technique, with three chambers placed in each of the three soil moisture regimes.

The mean net N mineralisation rate in the upper 13 cm of the soil was 132 mmol m^{-2} yr^{-1} in 1991 (Kjønaas et al., in press). The level corresponds well with a calculated value of net N mineralisation in the catchment based on uptake minus deposition. Net N_2O production was 1 mmol m^{-2} yr^{-1} in the period 1993 through 1994 (Klemedtsson et al., in press), and thus of minor importance for the total N budget.

3.3.3 Changes in pools and fluxes from 1930 to 1990

Very little information is available on the specific site and stand history over the period 1930 to 1990. The area surrounding lake Gårdsjön has supported a low level of grazing and extensive forestry for centuries, with major cutting of some areas in 1904 (Olsson, 1985). The mean age of the trees in the G2 NITREX catchment was roughly 104 years in 1991 (Kjønaas et al., in press), which suggests only a limited harvesting of trees in this catchment. In addition, reliable time trends are generally available only for bole production in forests, while information is generally lacking on development of the active crown compartment, variation in litterfall and the build-up of soil organic matter within a rotation cycle of a forest. The lack of good historical information on the development of a forest ecosystem is a major source of uncertainty in model calibration and hence predictions of future trends.

Total yearly increment of the tree biomass was calculated from differences in biomass of various tree compartments of 1990 and 1994 (Kjønaas et al., in press). The increment in the structural pool was slightly larger than increments given in production forestry yield class tables for *Picea abies* with similar site index, stand density, and age (Braastad, 1975). The comparable yield table was based on planted forests with 3 thinnings and a relatively intensive management. The relatively large increment found in the period from 1990 to 1994 includes four years of N addition. For this MERLIN application the naturally-generated forest at G2 NITREX catchment was assumed to be at nearly steady-state. Thus, the increment of structural wood was set to ½ the level given in the yield table of Braastad (1975).

The increment of the active "crown" pool is expected to be stable or slightly declining from canopy closure and onwards (Albrektson, 1980). The mean stand age in 1930 was 44 years, and the forest was assumed be close to canopy closure. Despite of the slight increase measured and estimated from Marklund’s biomass models for the period 1990-94, the initial modelling of the active tree pool was based on steady-state. With a stable active "crown" pool, the litter production was also assumed constant over time from 1930 to 1990.

As the active plant pool is considered to be in a steady state and the structural plant pool is set to have a steady but slow increase, the organic matter in the forest floor (LOM) and the mineral soil (ROM) is assumed to go through slow changes, with a build up of the forest floor through litterfall and an approximately equal decrease in ROM. The accumulation of organic matter in the LOM compartment was estimated using a model of Berg et al. (1995) for build up of organic matter in various types of coniferous forests, which includes data for above-ground litterfall and maximum decomposition rates of litter. A conservative value of 8% of above ground total litterfall was taken as the net amount of carbon annually accruing to the organic matter in the LOM pool; this amounts to an annual increase in LOM of 0.1% (about 0.95 molC m^{-2} yr^{-1}). The N required to build this LOM pool must come from ROM, as deposition inputs alone are insufficient. ROM is thus assumed to decrease in C from 1321 to 1226 mol m^{-2} and n from 40.9 to 38.0 mol m^{-2}, respectively, over the period 1930 to 1990. The N released from ROM moves to accumulating wood and especially the accumulating forest floor, by means of plant uptake followed by litterfall.

4. Description of MERLIN

MERLIN is a simple process-oriented model focused on simulating and predicting concentrations of inorganic nitrogen in soil leachate and runoff in terrestrial ecosystems (Cosby *et al.* 1997). The model links C and N cycles. The ecosystem is simplified to 2 plant compartments (active biomass such as foliage and roots and structural woody biomass) and 2 soil compartments (labile and refractory organic matter) (Figure 1). The C pools and fluxes are set external to the model. N pools and fluxes are then linked to C by C/N ratios in the pools. Transfer between compartments occurs by processes such as plant uptake, litterfall, immobilisation, mineralisation, nitrification and denitrification. There is no feedback between N status and C fluxes; this would be the next step in complexity. The key to MERLIN is that the rates of these processes are assumed to be governed by C/N ratios in the various pools. MERLIN is comprised of (1) a book-keeping procedure in which inputs and outputs of C and N to the ecosystem and between the 4 compartments are tallied, and (2) a series of simultaneously-operating processes that describe the transfer of C and N between the compartments and out of the ecosystem. The model is designed to function at annual time steps.

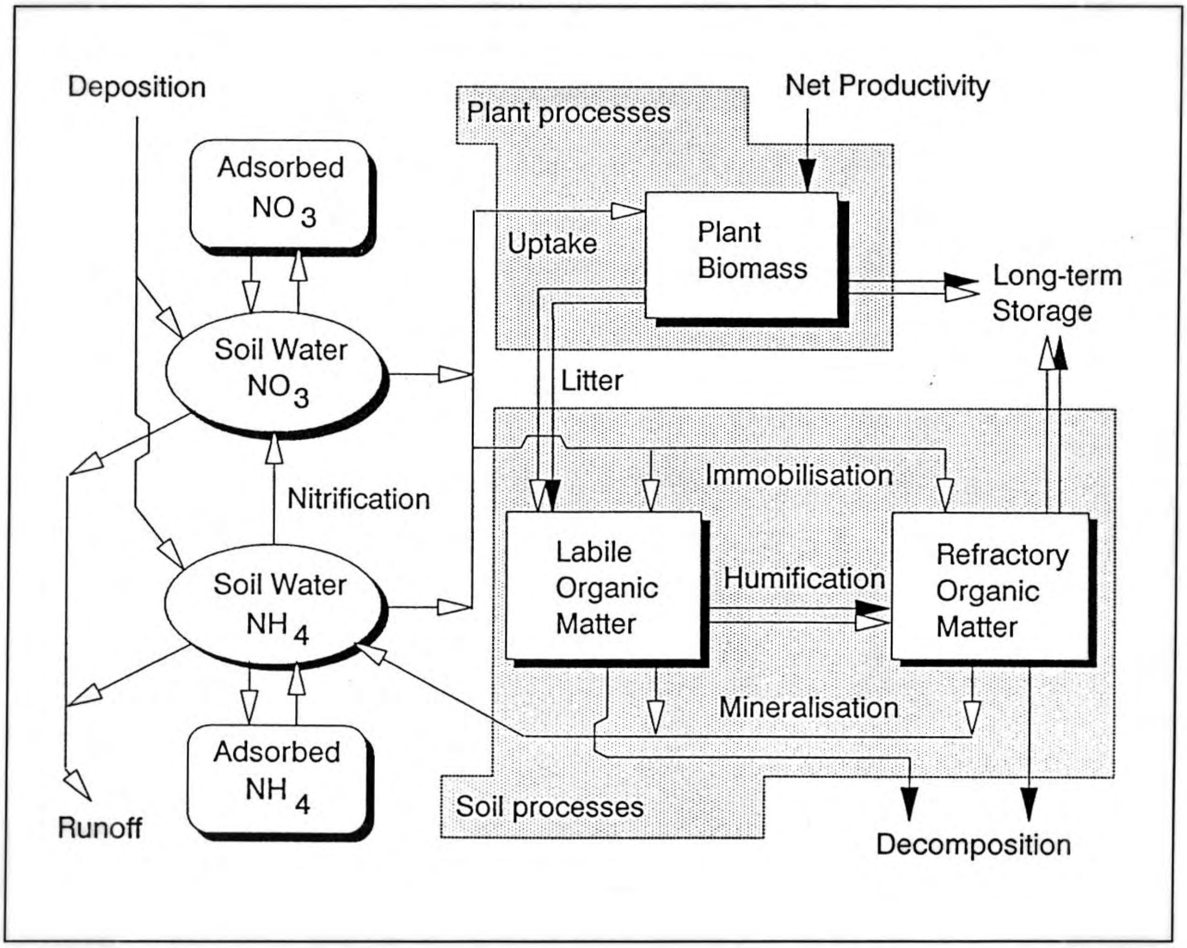


Figure 1. A schematic representation of the MERLIN model. Closed arrows represent fluxes of inorganic C; open arrows represent fluxes of inorganic N. Paired closed/open arrows represent fluxes of organic material containing both C and N (from Cosby *et al.* 1997.).

The model deals with NO_3, NH_4 and organic N. N inputs are as atmospheric deposition, fertilisers and N fixation. Time series of all inputs of inorganic N must be specified *a priori*. Nitrification, microbially-mediated transformation of NH_4 to NO_3, is represented in the model by a first-order reaction (1). The rate of loss of NH_4 is the product of a rate constant and the concentration of NH_4 at each time step:

$$FN_{nit} = NIT \times (NH_4)_{soil} \times SPV \tag{1}$$

where Fn_{nit} is the nitrifrication loss of NH_4 (mmol m^{-2} yr^{-1}), $(NH_4)_{soil}$ is the concentration of NH_4 in soil solution (mmol m^{-3}), NIT is the nitrification rate constant (y), and SPV is the pore volume per unit area of the soil (m). Adsorption of NH_4 on the soil matrix is modelled as a non-linear capacity-limited process using a Langmuir isotherm approach. N losses from the system are as inorganic in runoff and as gases (N_2O and N_2) from denitrification.

Plant biomass represents the aggregated pool of C and N present in the active portion of the ecosystem. The time series of net productivity is determined from specified time sequences of plant biomass, litter production and long-term storage such as wood production (Figure 1).

Plant growth requires N uptake from the soil as NH_4 and NO_3. Uptake is modelled as a non-linear Michaelis-Menten process that depends on the soil water concentration of NH_4 or NO_3 (2).

$$FNx_{upt,\,plt} = K_{mx,\,Nx,\,plt} \times \frac{(Nx)_{soil}}{(K_{hlf,\,Nx,\,plt} + (Nx)_{soil})} \qquad (2)$$

where $FNx_{upt,\,plt}$ is the uptake flux of inorganic N species by the plant compartment (mmol m^{-2} yr^{-1}), $(Nx)_{soil}$ is the concentration of inorganic N species in soil solution (mmol m^{-3}), $K_{mx,\,Nx,\,plt}$ is the maximum uptake rate (mmol m^{-2} yr^{-1}), and $K_{hlf,\,Nx,\,plt}$ is the half-saturation constant (the concentration of inorganic N species at which plant uptake proceeds at half the maximum rate; mmol m^{-3}). The maximum uptake rate is assumed to be proportional to the net primary productivity of the plants.

Soil organic material is divided into two compartments: labile organic matter (LOM) and refractory organic matter (ROM). Each is an aggregated pool of C and N representing accumulated organic compounds in the ecosystem. These materials provide the energy substrate for soil micro-organisms, which immobilise and mineralise C and N in soils (Figure 1). Microbial immobilisation of inorganic N is modelled as a non-linear Michaelis-Menten process that depends on the concentration of NH_4 or NO_3. The maximum immobilisation rate is assumed proportional to microbial secondary productivity.

Litter from the plant compartment enters the LOM pool. C and N leave this pool by decomposition (transformation of organic C to CO_2) and decay (degradation of the quality of the organic material). The decay products are passed on to the next compartment (ROM). Decomposition also occurs in ROM. The model requires input information for litter production, size of the carbon pool stored in LOM, and decomposition of LOM at each time step. In addition the size of the carbon pool stored in ROM is required.

These compartments and fluxes are highly aggregated. Conceptually the LOM pool represents that fraction of soil organic matter with relatively short turnover time (0-10 years), whereas ROM represents the fraction of soil organic matter with longer turnover time. The LOM pool may be most readily identified with the forest floor, but organic matter such decaying roots are also LOM and are found in deeper soil layers. LOM provides a soil organic matter compartment that can respond rather quickly to changing external conditions and inputs. The ROM pool, on the other hand, represents the bulk of C and N present in the rest of the soil profile. The long-term storage losses from the ROM represent losses of organic matter through leaching of dissolved organic compounds in drainage waters or peat formation.

Inputs required for MERLIN are temporal sequences of: 1) C fluxes and pools, 2) hydrologic discharge, and 3) external sources of inorganic N. Initial conditions (amounts of C and N) must be specified for each compartment. A number of «constants» (e.g. uptake parameters) are needed to specify the N dynamics of the organic compartments, and characteristics of the soils must be given (depth, porosity, bulk density, anion/cation exchange characteristics).

Outputs from MERLIN include: 1) concentrations and fluxes of NH_4 and NO_3 in soil water and runoff; 2) total N contents of the various compartments; 3) the C/N ratios of the aggregated plant and soil compartments; and 4) estimates of important processes in the N cycle (i.e. uptake, gross and net mineralisation and immobilisation).

5. Calibration procedure

The first step in calibration of MERLIN to a new site involves the compilation of C and N pool and flux data for the site at the present-day (termed reference year) and at one or more points in time in the past. Generally the model is run for 50-100 years starting at a point in time (termed background year) at which the N deposition is low and constant (often the assumed background level). The necessary data are collected in a spreadsheet by which the entire C and N cycles are calculated and checked for internal consistency. For this calibration at Gårdsjön such spreadsheets for the background year 1930 and the reference year 1990 were compiled (Appendix A).

The next step is to define the time sequences of changes of pools and fluxes. For this application the changes assumed were in the LOM pool (by increasing in C 0.95 mol m^{-2} yr^{-1} with C/N ratio of the ambient LOM, Appendix A), the wood pool (by increasing 3.55 mol m^{-2} yr^{-1} with C/N ratio of 336, Appendix A), and the N deposition (increasing from 1930 to 1990 following estimates of A. Semb NILU, pers. comm.). Changes in ROM pool are calculated by MERLIN at each time step to balance the carbon budget.

Calibration of MERLIN then involves adjusting the parameters for the 3 N uptake functions: plants, LOM and ROM. The position of the Michaelis-Menten uptake curve (C/N reference), the steepness of the curve (half-width and C/N optimum) and the height of the curve (reference K2) can be adjusted. For each trial the model is run from starting values in 1930 to 1990 and the suitability of the calibration is subjectively judged with respect to the best fit for:
(1) carbon pools in 1990 agree with observed;
(2) C/N ratios in the pools in 1990 agree with observed;
(3) changes in C/N ratios over the 60-year period are acceptable;
(4) N output (stream) over the 60-year period is acceptable.

A print-out of the parameter values and table of pools and fluxes for the Gårdsjön G2 NITREX calibration is given in Appendix B.

The calibrated model is then used to predict the changes following N additions of the NITREX experiment. Because very little happens with N cycling and fluxes in the forest ecosystem during the hindcast period 1930 to 1990, the model is poorly constrained. There are many possible sets of parameters that will give a satisfactory fit to the measured 1990 data. This is in contrast to the MERLIN calibration at Aber forest in Wales, UK, where the model had to correctly fit the complicated history of the site (former moorland ploughed and planted with a 30-year old vigorously growing forest) (Emmett et al. in press).

At Gårdsjön the final calibration therefore made use of results from the first 4 years of N additions (1991-1994). The measured deposition and hydrologic discharge values were used to drive the model for the years 1989-94 (period of observation). Here the focus is on changes in N concentrations in streamwater, and the additional constraint was provided by the 4-year record of N leaching in response to the N additions (Table 1) (Moldan and Wright in press). The data suggest a slow but accelerating increase in N flux in runoff, and this is obtained by adjusting the parameters of the function for immobilisation in LOM.

The calibrated model is then evaluated with the runoff data for the 5th and 6th years of treatment (1995 and 1996) (F. Moldan, pers. comm.). The year 1995 was unusually dry, and this is reflected in lower deposition (less N added) and lower runoff of N in both the model and measuremnts. The year 6 was hydrologically normal, yet the measured runoff flux of N was only 12 mmol m^{-2} yr^{-1}, about the same level as 1994 and 1995. MERLIN predicts a much higher flux than observed.

Table 1. Fluxes of nitrogen species in throughfall (tf) and runoff during the 2-year pre-treatment period April 1989 - March 1991 (denoted 1989 and 1990), and 6 years of treatment April 1991 - March 1997 (1991, 1992, 1993, 1994, 1995, 1996) at catchments F1 CONTROL and G2 NITREX. Data from Moldan and Wright (in press) and F. Moldan (pers. comm.). Units: $mmol_c\ m^{-2}\ yr^{-1}$ ($1\ mmol_c = 1$ meq; $1\ mmol\ m^{-2}\ yr^{-1} = 0.14\ kg\ ha^{-1}\ yr^{-1}$).

	F1 CONTROL				G2 NITREX			
	NO3		NH4		NO3		NH4	
	in tf	out runoff	in tf	out runoff	in tf	out runoff	in tf	out runoff
pre-treatment								
1989	66	1	37	0	63	0	33	0
1990	51	0	26	0	42	0	21	0
treatment								
1991	56	1	32	0	169	2	151	1
1992	51	0	22	1	185	4	159	1
1993	36	1	17	2	194	17	184	2
1994	51	1	28	1	221	21	197	3
1995	41	0	22	1	149	9	134	4
1996	57	0	48	0	194	11	185	1

6. Results and discussion

The forest history at Gårdsjön is somewhat uncertain. Part of the forest was possibly cut about 1904 and the present stand has developed with relatively little cutting since (Olsson 1985). The year 1930 was chosen as the start of the calibration as at this time the forest was presumably close to canopy closure, but the large increases in nitrogen deposition had not yet begun. The results of the calibration thus reflect a relatively stable situation from 1930 to the onset of increased N deposition in 1950 (Figure 2a), at which time N concentration of the 3 pools (plants, LOM and ROM) start to change Figure 2b).

As the forest slowly grows and matures during the 60-year period 1930-90, a small amount of N is stored in the boles of the trees (0.6 mol m^{-2}) and lost as dissolved organic N (DON) to runoff (0.7 mol m^{-2}). The forest floor is assumed to build thus increasing the N stored in LOM by 3.7 mol m^{-2}. The N required comes in part from N deposition (2.5 mol m^{-2}), via immobilisation and release of deposited N in the forest floor, and the remainder is assumed to come from ROM (2.6 mol m^{-2}) (Table 2).

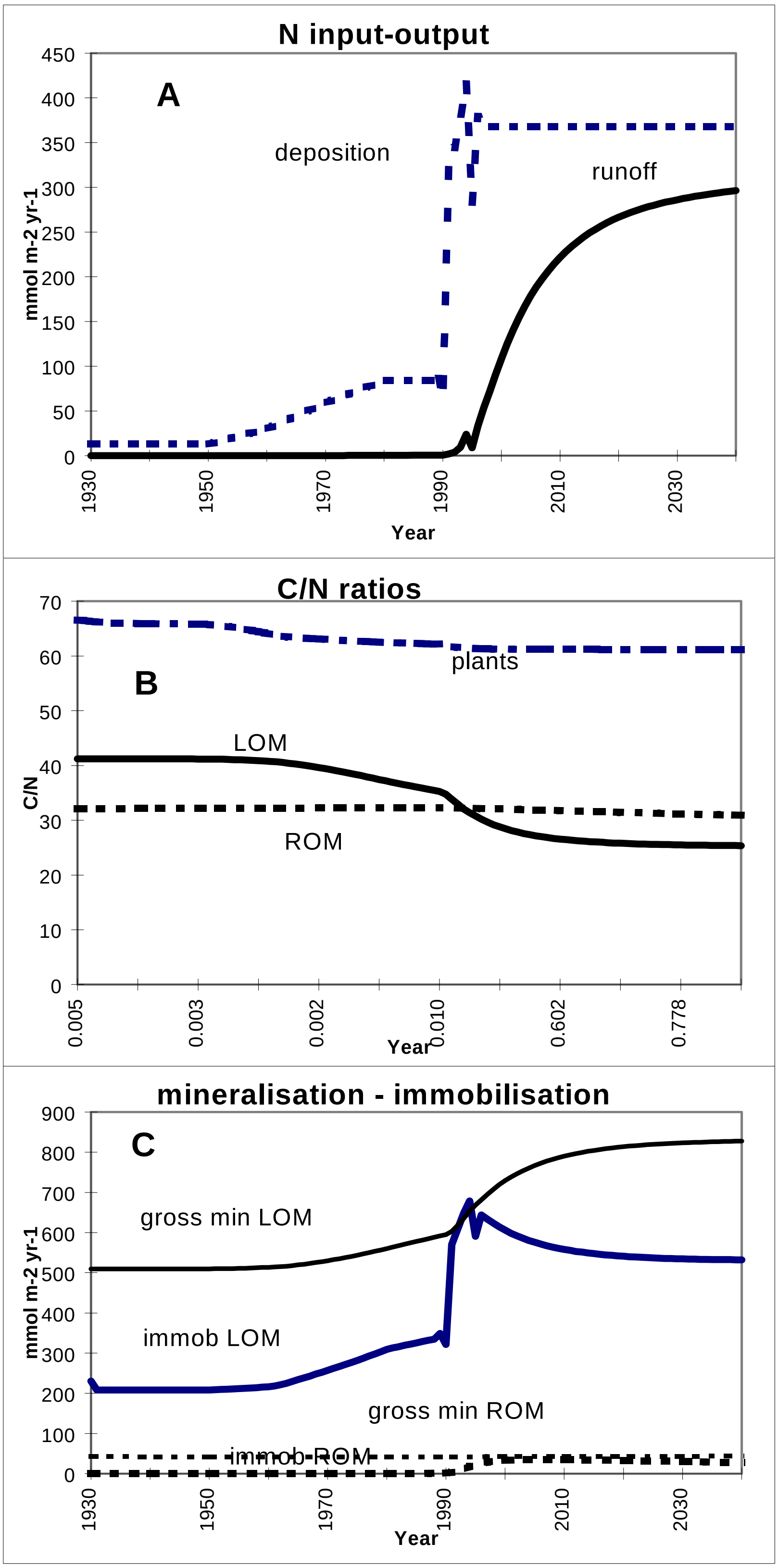


Figure 2. Results of MERLIN calibration and prediction for G2 NITREX catchment at Gårdsjön. Panel A. Deposition and runoff. Panel B. C/N ratios in the 3 pools. Panel C. Gross mineralisation and immobilisation in LOM and ROM.

Table 2. Nitrogen pools in 4 key years (1930 prior to increased N deposition, 1990 prior to NITREX treatment, 1995 after 5 years of N additions, and 2030 after 40 years of N additions) and total fluxes between the years as measured (1990) and estimated by MERLIN (1930, 1995 and 2030). Units: mol m^{-2}.

	1930		1990		1995		2030
plants	1.5		1.6		1.6		1.6
LOM	7.6		11.3		12.9		17.8
ROM	50.6		38.0		38.0		37.6
🖓 pools		+1.2		+1.6		+4.5	
🖓 wood		+0.6		+0.1		+0.4	
💧 loss DON		+0.7		0		+0.4	
💧 deposition		2.5		1.7		12.9	
💧 runoff		0		0.1		7.4	

This “mining” of ROM to supply the N necessary for growth of the trees and to build forest floor is probably a natural feature of boreal forests (Johnson 1992). A “mining” of ROM during a life cycle was also suggested in a study of N content in the soil profile under Norway spruce at Nordmoen, Norway, of different stand ages (Sogn et al., in prep.). Presumably N is translocated from ROM to LOM via the plants (uptake then litterfall) during the entire aggrading phase of the forest, and then returned to ROM (via LOM) following natural disturbance such as forest fire or windthrow, in addition to the slow transport of dissolved organic N down through the soil profile. In any case most forests retain the N in the system very efficiently, such that in the absence of excess N deposition there is very little N entering the system and very little lost.

The reconstructed N cycle for the year 1930 at Gårdsjön G2 NITREX catchment reflects the assumption that the forest is slowly aggrading but is otherwise at steady-state (Appendix A). The small amounts of N required for wood production (11 mmol m^{-2} yr^{-1}) and lost annually as DON in runoff (11 mmol m^{-2} yr^{-1}) are compensated by small (“background”) deposition of N (13 mmol m^{-2} yr^{-1}) and mining of ROM (8 mmol m^{-2} yr^{-1}).

Measurements of mineralisation provide another constraint for the calibration of MERLIN. Net mineralisation in LOM in 1990 is estimated at 132 mmol m^{-2} yr^{-1} (Kjønaas et al., in press), somewhat lower than the simulated value of 250 mmol m^{-2} yr^{-1} given by MERLIN (Figure 2). The predicted net mineralisation of 1995 is, however, lower than the values indicated by *in situ* mineralisation studies in 1995 (Kjønaas and Svensson, in prep). The predicted net mineralisation of ROM decreases from 1990 onwards, while the gross mineralisation stays fairly constant (Figure 2).The mechanisms controlling these processes are not clear, and another possibility could be a reduction in gross mineralisation along with a lower N immobilisation than indicated by the model. The result would be a similar reduction in net mineralisation. This process would be in accordance with Berg (1986) who found a decrease in decomposition of old lignin-rich organic substances with increased nitrogen availability.

The calibrated model indicates that most of the changes in N leached are related to changes in N status of LOM. Very little of the added N goes to the plants. This is in accordance with measured N concentration in needles, where no response to N addition was observed between 1990 and 1995 (Kjønaas et al., in press). The steady state from 1990 to 2030 reflects partially an old forest with slow growth, and partially an expected gradually dieback of older trees in the catchment. The understorey vegetation has not been included in this model run, and a small fraction of the added N probably is taken up by the understorey vegetation. Nevertheless, most of the added N goes to LOM. The ROM pool is relatively large and reacts so slowly that it is not expected to have a significant impact over the short term (1-10 years).

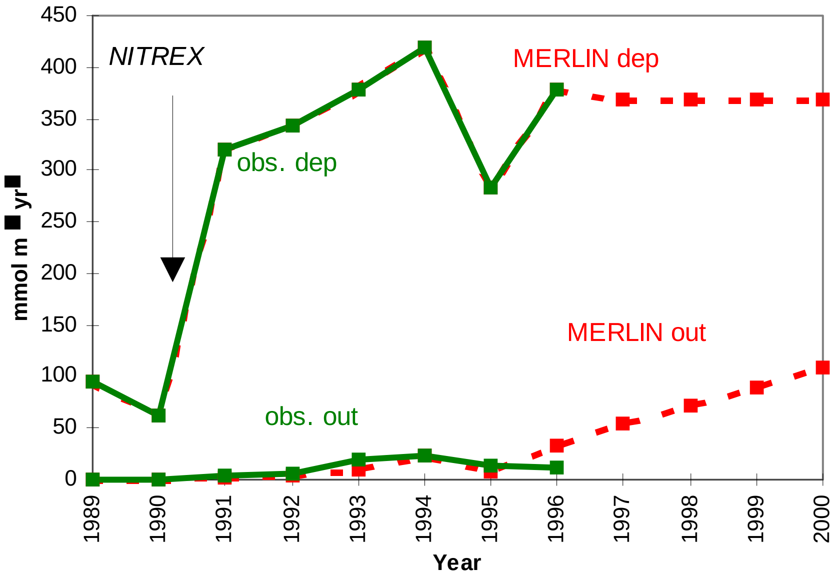
Leaching of dissolved inorganic nitrogen (DIN) started at the onset of N addition in 1991 and increased steadily during the 4 treatment years used for calibration of the model (Figure 3). The simulated leaching of DIN continues this trend. Several factors affect the leaching of DIN. The amount of N applied, the hydrological status of the catchment at the time of addition, and the discharge level, are all factors of importance for the outflux of DIN on a short term basis (Moldan and Wright, in press). In addition, the increased N in runoff does not reflect the ecosystem's nitrogen status, as the forest system has had a limited time to respond to the sudden dramatic nitrogen addition. On a long term basis, it is the change in major processes such as the ratio of gross NH_4 and NO_3 immobilisation to gross mineralisation, and the soil C/N ratio that is expected to determine the leaching level (Aber, 1992).

The calibrated model correctly predicts the measured N flux in runoff in 1995, the 5th year of treatment. That year was unusually dry, with lower N deposition and very low runoff. The following year 1996 was hydrologically normal, and MERLIN predicts a resumption of the trend of increasing N flux in runoff, but the measured flux was only 12 mol N m^{-2}, about the same level as 1994 and 1995. We have no explanation for the low measured flux in 1996. Additional years of treatment are necessary to determine whether the increasing trend is broken, and to fully evaluate the predictive capabilities of MERLIN.

A difference between predicted and measured N leaching from the G2 NITREX catchment may partially reflect differences between calibrated and observed C/N ratio in the forest floor. The model uses the C/N measured in forest floor as a proxy for the C/N ratio of the actual substrate used by soil microbes. In the MERLIN model, significant leaching occurs as the C/N ratio in LOM is decreased from the 1990 value of about 31 to about 25. This relation between C/N ratio and N leaching agrees with the general results from the European NITREX sites, at which it appears that significant N leaching occurs at sites with low C/N ratios in forest floor (high N status), and little or no N leaching at sites with high C/N ratios in forest floor (low N status) (Gundersen et al., in press) (Figure 4).

Emmett et al. (In press) point out that the MERLIN model may be used for predictive purposes as long as there is no major biological change that would be expected to cause a change in relationships between the uptake by the plants and soil and their C/N ratios. The onset of nitrate leaching from the Gårdsjön NITREX catchment was induced mainly by adjusting the C/N optimum from 30 to below 25 in the calibration. The time needed for a system to change from being N limited, indicated by high C/N in LOM, to a N rich system, with a C/N below 25, is uncertain, and the processes that govern the transition are not fully understood. Both the rate and capacity of nitrogen assimilation as well as the response of the carbon dynamics are inadequately known. An investigation of the N content and C/N ratio under different stand ages of Norway spruce at Nordmoen near Oslo, Norway, showed no changes in the C/N of LOM within a rotation cycle (Sogn et al, in prep). A change in the soil C/N seemed to take place fairly slowly even with large additions of fertiliser N (Sogn et al, in prep). Assuming a constant carbon pool and an annual N input and assimilation of 50 kg N ha^{-1} yr^{-1} in the Gårdsjön NITREX catchment, a decrease in the C/N ratio from 35 to 25 will take approximately 60 years (Figure 4). Since the gradual change of the target C/N ratio is uncertain, and this value is needed as a parameter for predictive purposes of nitrate leaching connected to ecosystem changes, the model has a limited ability to predict N "saturation" in Scandinavian coniferous forests with high C/N ratios. A sensitivity analysis is needed, along with further testing on a variety of forest ecosystems evaluate the utility of the model.

The results from MERLIN indicate trends in N pools and fluxes in plants, soil and runoff compatible with independent measurements including other N experiments at NITREX sites and elsewhere. In general these all show that most of the added N goes to LOM, that foliage shows a moderate and



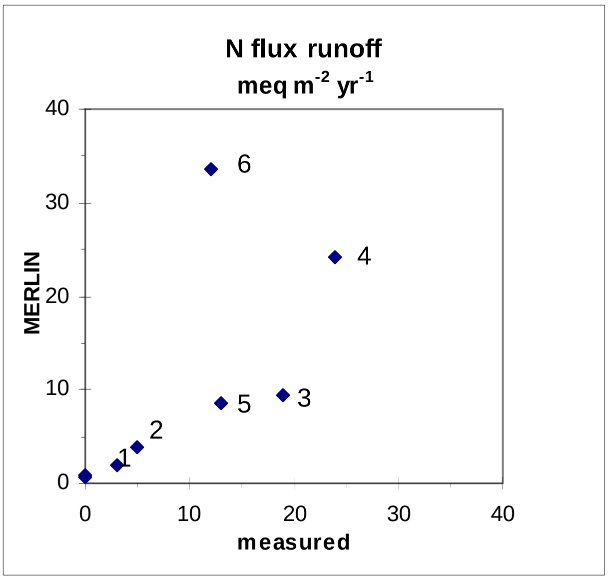


Figure 3. Top panel: Deposition and output fluxes of inorganic N at the catchment G2 NITREX as measured (Moldan and Wright, in press), calibrated (1989-1994), and simulated by MERLIN (1995-2000). Deposition value used in MERLIN for 1996 onwards was post-treatment mean (1991-96). Bottom panel: N flux in runoff measured and modelled for the 6 years of treatment.

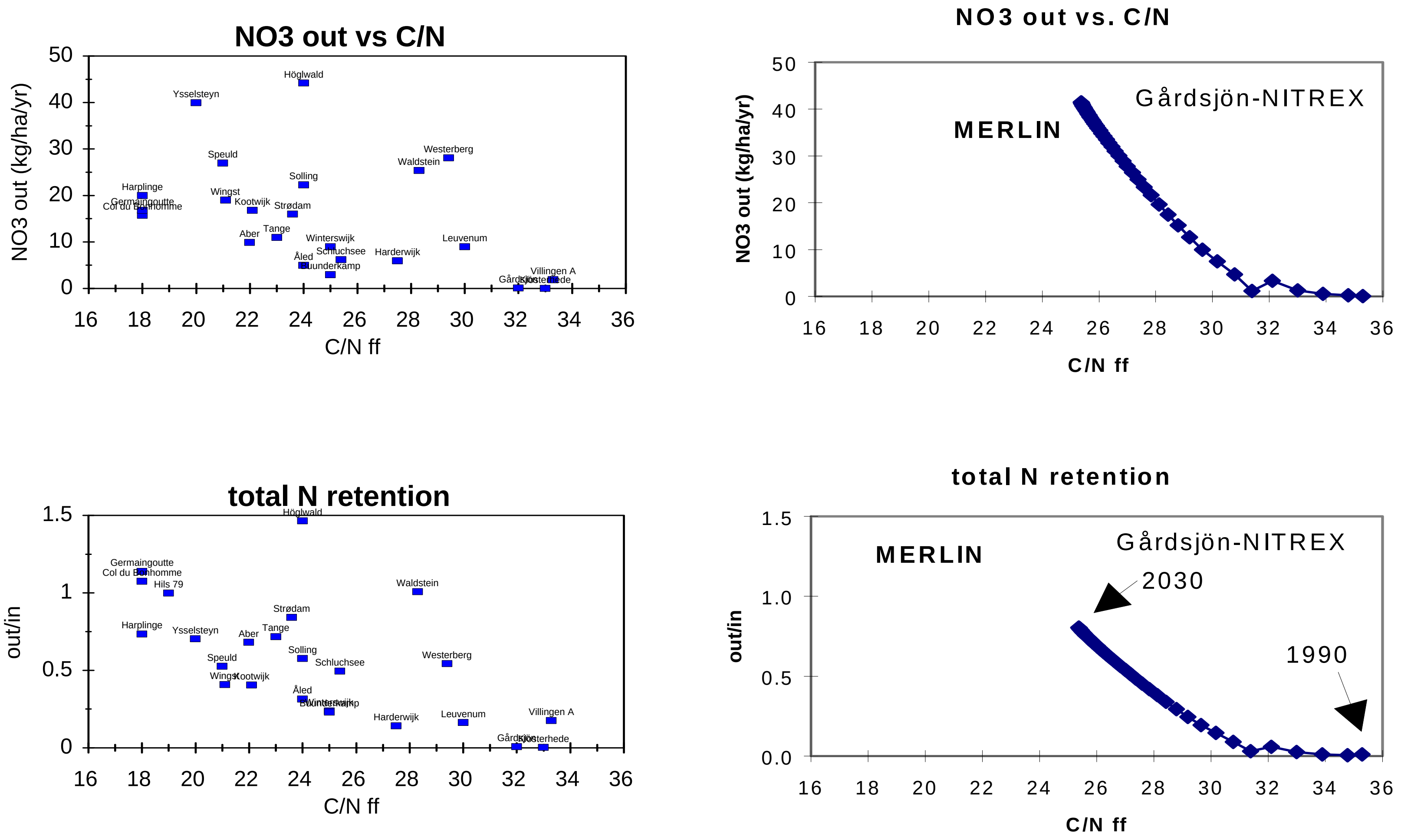


Figure 4. N flux out and ratio of output to input of inorganic N at forested sites in Europe in the 1990’s (data from the ECOFEE data base of P. Gundersen, pers. comm.) and as predicted by MERLIN for the Gårdsjön NITREX catchment from the year 1990 to the year 2030.

delayed response, and that leachate is a significant path for excess N in N-rich systems receiving high N deposition (Tietema et al. in press). This application of MERLIN corroborates the calibration at Aber forest (Emmett et al., in press) in that both point to the basic lack of sufficient information on C and N cycling in forests and especially the changes in pools and fluxes during cycles of forest growth and harvesting. Traditional forest studies focus on wood production. Litter production, build-up of LOM and changes in ROM over the lifetime of a forest are poorly known. Studies such as the survey of Sitka spruce stands of different ages in Wales (Emmett et al. 1993, Stevens et al. 1994) are urgently required for other major tree species such as Norway spruce and Scots pine.

The model is a useful tool for bookkeeping of nitrogen pools and fluxes, and it is an important contribution to further development of qualitative understanding of the N cycle in forests. As this application to G2 NITREX catchment at Gårdsjön is only the second site at which the model has been used, it is yet pre-mature to make generalisations on the utility and robustness of the model. Future applications scheduled include other NITREX sites (Speuld in the Netherlands, Klosterhede in Denmark), the RAIN/CLIMEX site at Risdalsheia in Norway, and several sites in North America (Smoky Mountain Nation Park, Tennessee, USA, and Bear Brook, Maine, USA). Together these applications should reveal whether only a narrow range of values for key parameters can satisfactorily explain the observed ecosystem effects, and in particular whether the major aspects of ecosystem behaviour following changes in N deposition can be accounted for by changes in mineralisation and immobilisation in LOM.

7. Acknowledgements

We thank F. Moldan and A. Stuanes for professional assistance and K. Nadelhoffer for useful comments. This research was funded principally by the Norwegian Research Council (NFR) (108044/720, TVLF 95-26/95-25) and in part by the Swedish Environmental Protection Board (SNV), the Commission of European Communities (EV5V-CT930264 and EV5V-CT940436), the U.S. Department of Energy through contract DE-FG02-92ER30196 with E & S Environmental Chemistry, Inc., the Norwegian Institute for Forest Research (NISK), and the Norwegian Institute for Water Research (NIVA)

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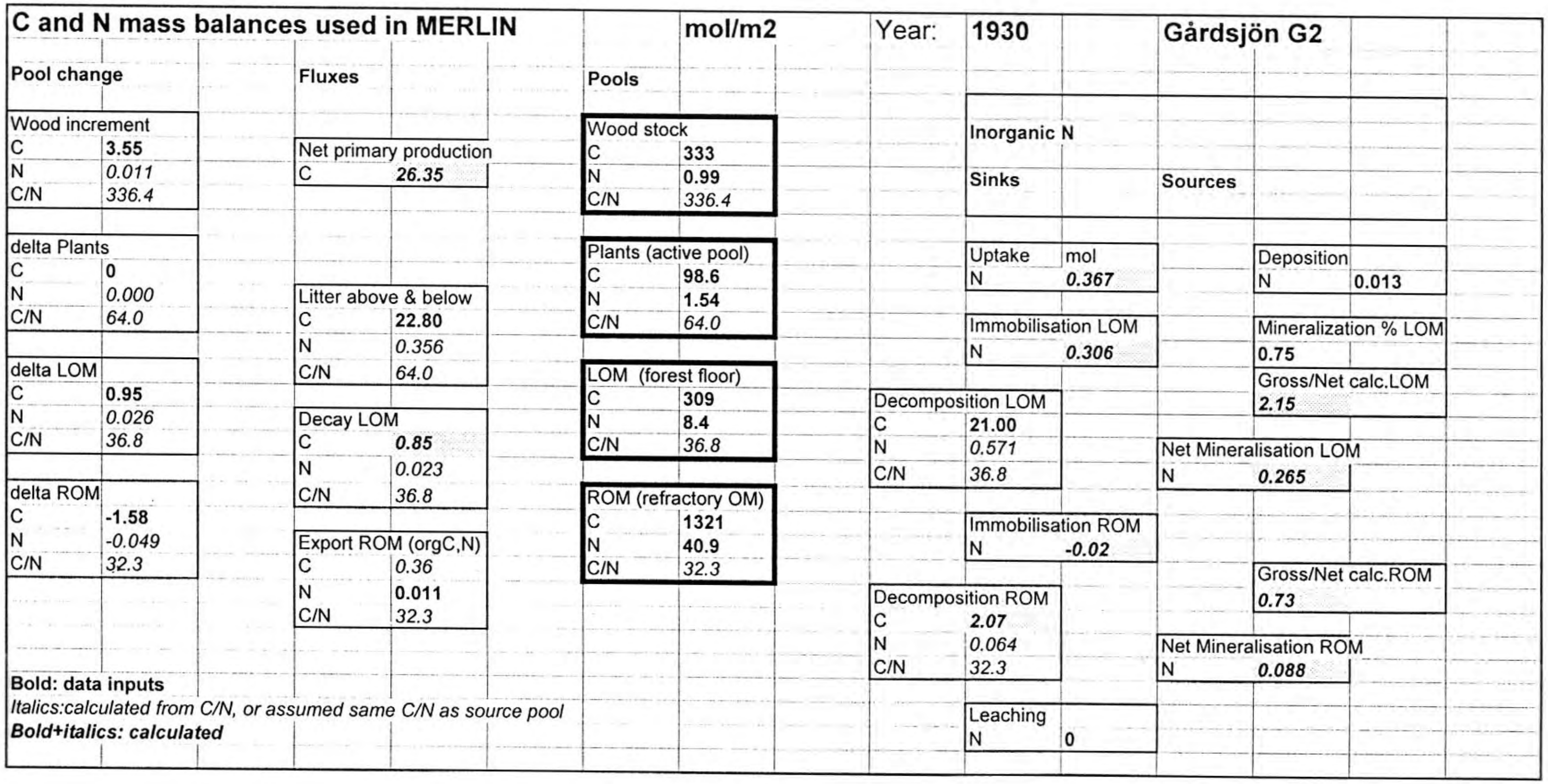
Appendix A. C and N mass balances used in MERLIN

Shown are spreadsheets for 2 key years, 1930 and 1990.

Table 1 shows year 1930, the start of the hindcast period at which time the forest was about 40 years-old, probably had reached canopy closure, and was in a state of slow aggradation.

Table 2 shows the year 1990, the end of the hindcast period and last year prior to N addition. Now the forest is about 100 years-old and still slowly aggrading.

The C and N cycles are calculated from measured (or estimated) values for several parameters. These are shown in **bold** and include estimates for C and N contents of the 2 plant and 2 soil compartments outlined in bold at the centre, the annual C increment to these pools (left-hand column), and the deposition and leaching (right-hand column). In addition the fractions of total mineralisation occurring in LOM and ROM must be specified. All other values are calculated from these, either from mass-balance considerations or from assumptions about C/N ratios. The column at the left shows the annual incremental change in the pools, the next column gives the fluxes between the pools. The columns to the right of the pools show the sinks and sources. The details of the calculations are given in Table 3.



C and N mass balances used in MERLIN **mol/m2** Year: **1930** **Gårdsjön G2**

Pool change

Wood increment	
C	**3.55**
N	*0.011*
C/N	*336.4*

delta Plants	
C	**0**
N	*0.000*
C/N	*64.0*

delta LOM	
C	**0.95**
N	*0.026*
C/N	*36.8*

delta ROM	
C	**-1.58**
N	*-0.049*
C/N	*32.3*

Fluxes

Net primary production	
C	***26.35***

Litter above & below	
C	**22.80**
N	*0.356*
C/N	*64.0*

Decay LOM	
C	***0.85***
N	*0.023*
C/N	*36.8*

Export ROM (orgC,N)	
C	*0.36*
N	**0.011**
C/N	*32.3*

Pools

Wood stock	
C	**333**
N	**0.99**
C/N	*336.4*

Plants (active pool)	
C	**98.6**
N	**1.54**
C/N	*64.0*

LOM (forest floor)	
C	**309**
N	**8.4**
C/N	*36.8*

ROM (refractory OM)	
C	**1321**
N	**40.9**
C/N	*32.3*

Inorganic N

Sinks

Uptake	mol
N	***0.367***

Immobilisation LOM	
N	***0.306***

Decomposition LOM	
C	**21.00**
N	*0.571*
C/N	*36.8*

Immobilisation ROM	
N	***-0.02***

Decomposition ROM	
C	***2.07***
N	*0.064*
C/N	*32.3*

Leaching	
N	**0**

Sources

Deposition	
N	**0.013**

Mineralization % LOM
0.75

Gross/Net calc.LOM
2.15

Net Mineralisation LOM	
N	***0.265***

Gross/Net calc.ROM
0.73

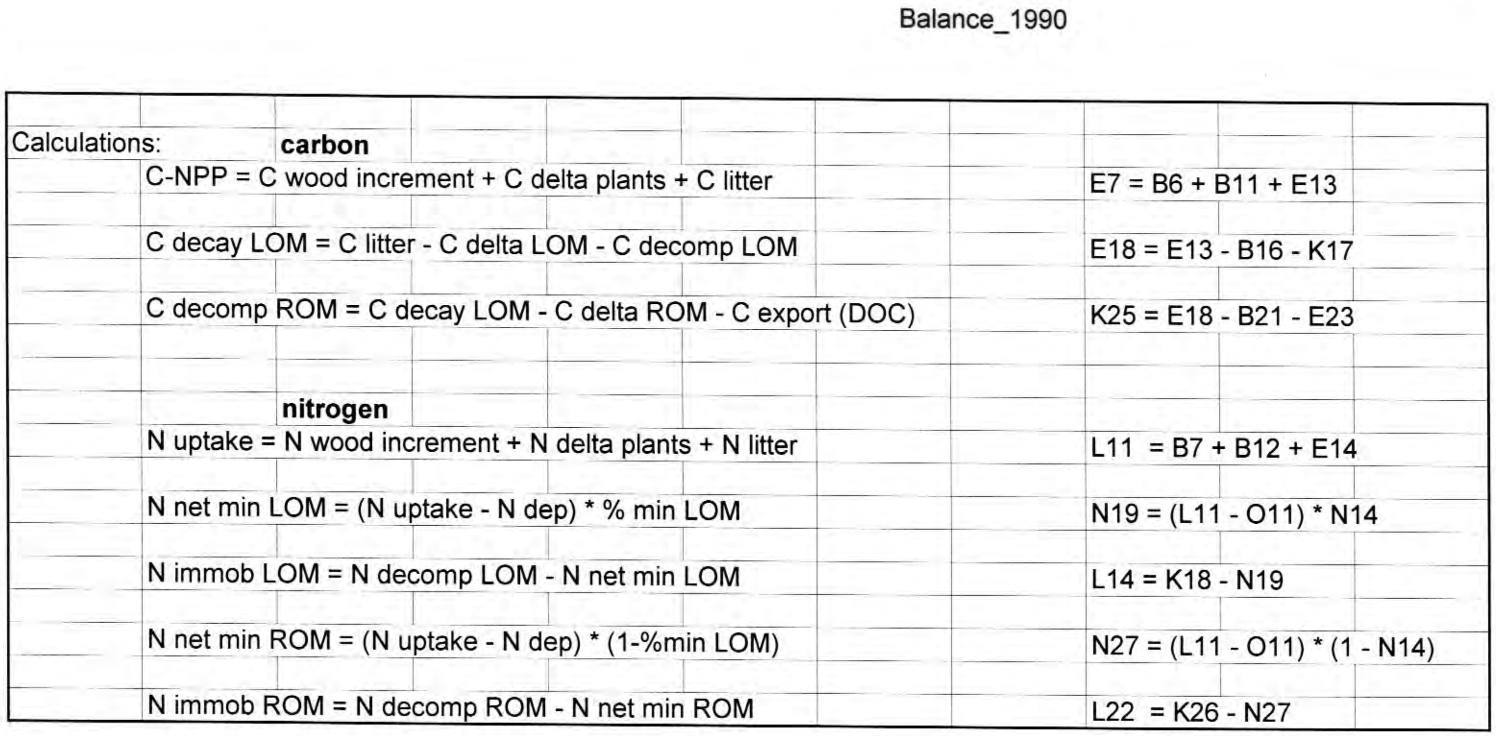
Net Mineralisation ROM	
N	***0.088***

Bold: data inputs

Italics:calculated from C/N, or assumed same C/N as source pool

Bold+italics: calculated

C and N mass balances used in MERLIN					**mol/m2**	Year:	**1990**		**Gårdsjön G2**		
Pool change		**Fluxes**		**Pools**							
Wood increment				Wood stock			**Inorganic N**				
C	**3.55**	Net primary production		C	**546**						
N	*0.011*	C	***26.35***	N	**1.63**		**Sinks**		**Sources**		
C/N	*335.0*			C/N	*335.0*						
delta Plants				Plants (active pool)			Uptake	mol		Deposition	
C	**0**			C	**98.6**		N	***0.376***		N	**0.084**
N	*0.000*	Litter above & below		N	**1.58**						
C/N	*62.4*	C	**22.80**	C/N	*62.4*		Immobilisation LOM			Mineralization % LOM	
		N	*0.365*				N	***0.379***		**0.75**	
delta LOM		C/N	*62.4*	LOM (forest floor)						Gross/Net calc.LOM	
C	**0.95**			C	**397**	Decomposition LOM				***2.73***	
N	*0.027*	Decay LOM		N	**11.3**	C	**21.00**				
C/N	*35.1*	C	***0.85***	C/N	*35.1*	N	*0.598*		Net Mineralisation LOM		
		N	*0.024*			C/N	*35.1*		N	***0.219***	
delta ROM		C/N	*35.1*	ROM (refractory OM)							
C	**-1.58**			C	**1226**		Immobilisation ROM				
N	*-0.049*	Export ROM (orgC,N)		N	**38.0**		N	***-0.01***			
C/N	*32.3*	C	*0.35*	C/N	*32.3*					Gross/Net calc.ROM	
		N	**0.011**			Decomposition ROM				***0.88***	
		C/N	*32.3*			C	***2.08***				
						N	*0.064*		Net Mineralisation ROM		
Bold: data inputs						C/N	*32.3*		N	***0.073***	
Italics:calculated from C/N, or assumed same C/N as source pool							Leaching				
Bold+italics: calculated							N	**0**			



Balance_1990

Calculations: **carbon**

C-NPP = C wood increment + C delta plants + C litter — E7 = B6 + B11 + E13

C decay LOM = C litter - C delta LOM - C decomp LOM — E18 = E13 - B16 - K17

C decomp ROM = C decay LOM - C delta ROM - C export (DOC) — K25 = E18 - B21 - E23

nitrogen

N uptake = N wood increment + N delta plants + N litter — L11 = B7 + B12 + E14

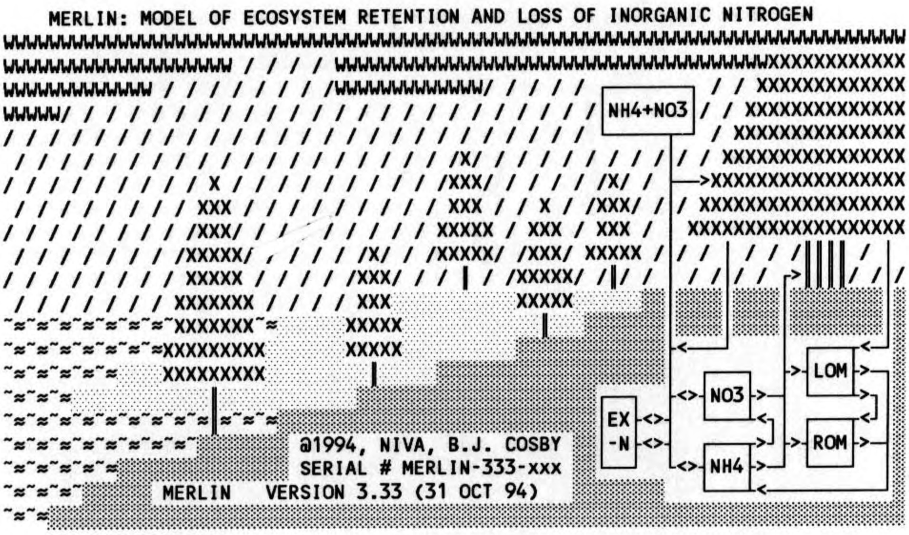
N net min LOM = (N uptake - N dep) * % min LOM — N19 = (L11 - O11) * N14

N immob LOM = N decomp LOM - N net min LOM — L14 = K18 - N19

N net min ROM = (N uptake - N dep) * (1-%min LOM) — N27 = (L11 - O11) * (1 - N14)

N immob ROM = N decomp ROM - N net min ROM — L22 = K26 - N27

Appendix B. Parameter values for calibration of MERLIN to Gårdsjön G2 NITREX



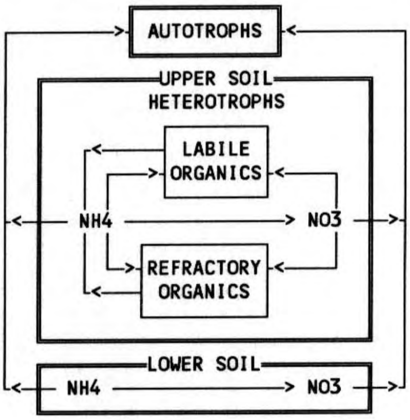
MERLIN: MODEL OF ECOSYSTEM RETENTION AND LOSS OF INORGANIC NITROGEN

@1994, NIVA, B.J. COSBY
SERIAL # MERLIN-333-xxx
MERLIN VERSION 3.33 (31 OCT 94)

FOUR PROCESSES CONTROL INORGANIC NITROGEN SPECIATION AND EXCHANGE BETWEEN BIOMASS POOLS AND THE SOILS.

UPTAKE: REMOVAL OF NO3 AND NH4 FROM SOIL
  BY AUTOTROPHS (CAN BE FROM BOTH SOILS)
IMMOBILIZATION: REMOVAL OF NO3 AND NH4
  BY HETEROTROPHS (FROM UPPER SOIL ONLY)
MINERALIZATION: RELEASE OF NH4 INTO SOIL
  (TO THE UPPER SOIL ONLY)
NITRIFICATION: CONVERSION OF NH4 TO NO3
  (CAN OCCUR IN BOTH SOILS)

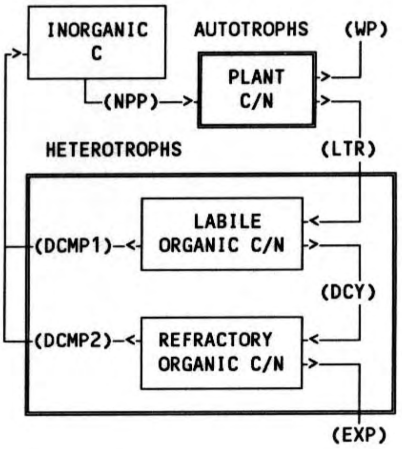
UPTAKE AND IMMOBILIZATION ARE NONLINEAR FUNCTIONS OF SOIL N CONCENTRATION, C/N OF BIOMASS, AND CARBON PRODUCTIVITY
MINERALIZATION IS A LINEAR FUNCTION OF DECOMPOSITION AND C/N OF BIOMASS

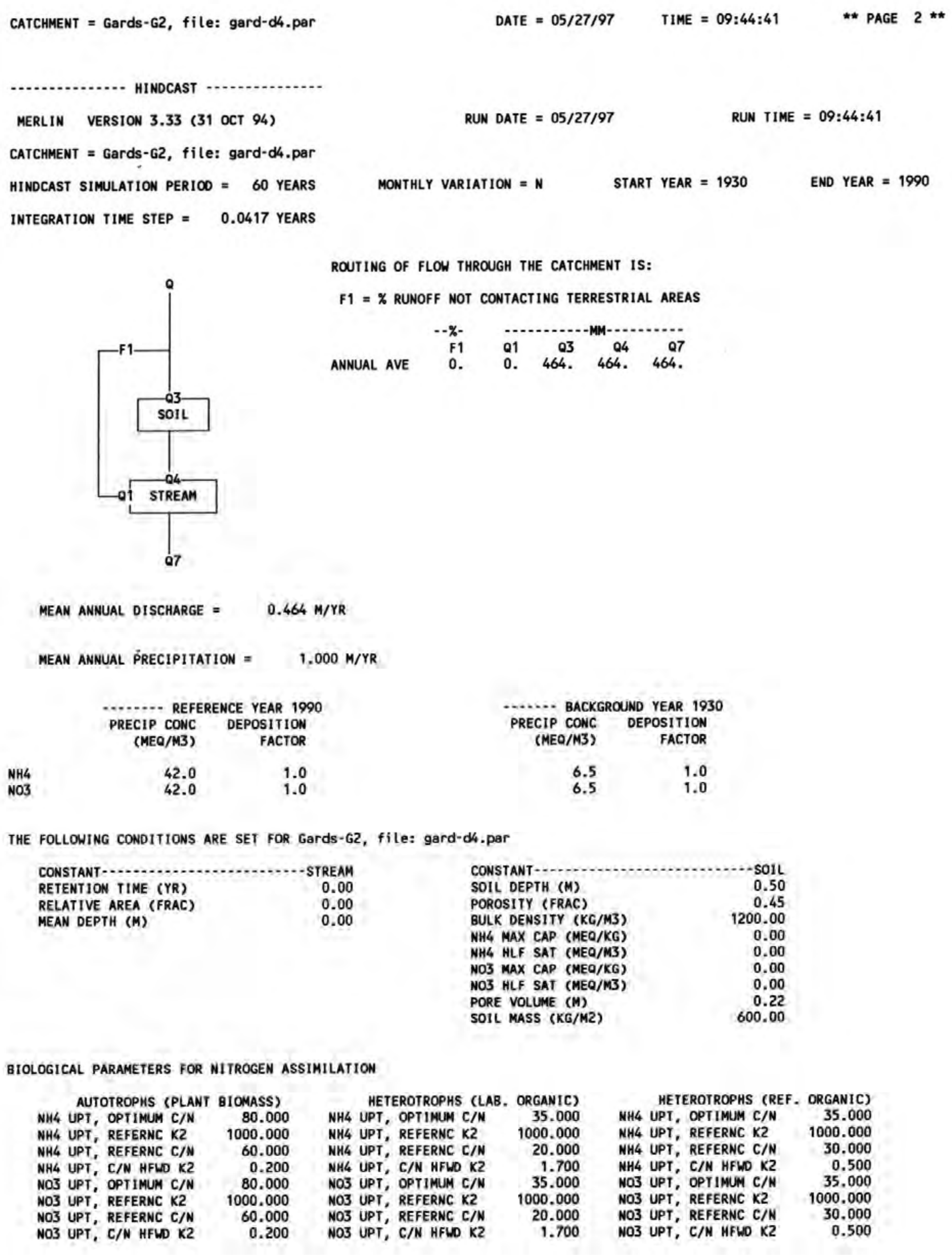


SEVEN FLUXES CONTROL THE CARBON CONTENT OF THE AGGREGATED BIOMASS POOLS.

-(NPP) NET PRIMARY PRODUCTION
-(WP) WOOD PRODUCTION
-(LTR) LITTER PRODUCTION
-(DCY) DECAY OF LABILE ORGANIC MATTER, CONVERTED TO REFRACTORY ORGANIC MATTER
-(DCMP1 & DCMP2) DECOMPOSITION OF LABILE AND REFRACTORY ORGANIC MATTER
-(EXP) ORGANIC MATTER EXPORT FROM SOIL

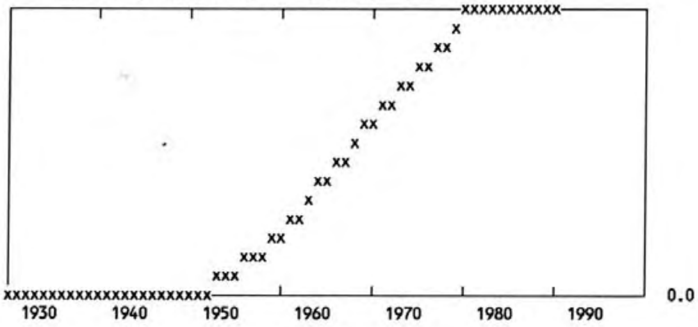
CARBON FLUXES (MOL/M2/T) AND/OR POOL SIZES (MOL/M2) MUST BE SPECIFIED.
CARBON FLUXES TRANSPORT NITROGEN BY MOVING ORGANIC-N ALONG WITH CARBON IN THE RATIO OF C/N IN THE SOURCE BIOMASS (OR BY USING A SPECIFIED C/N RATIO).



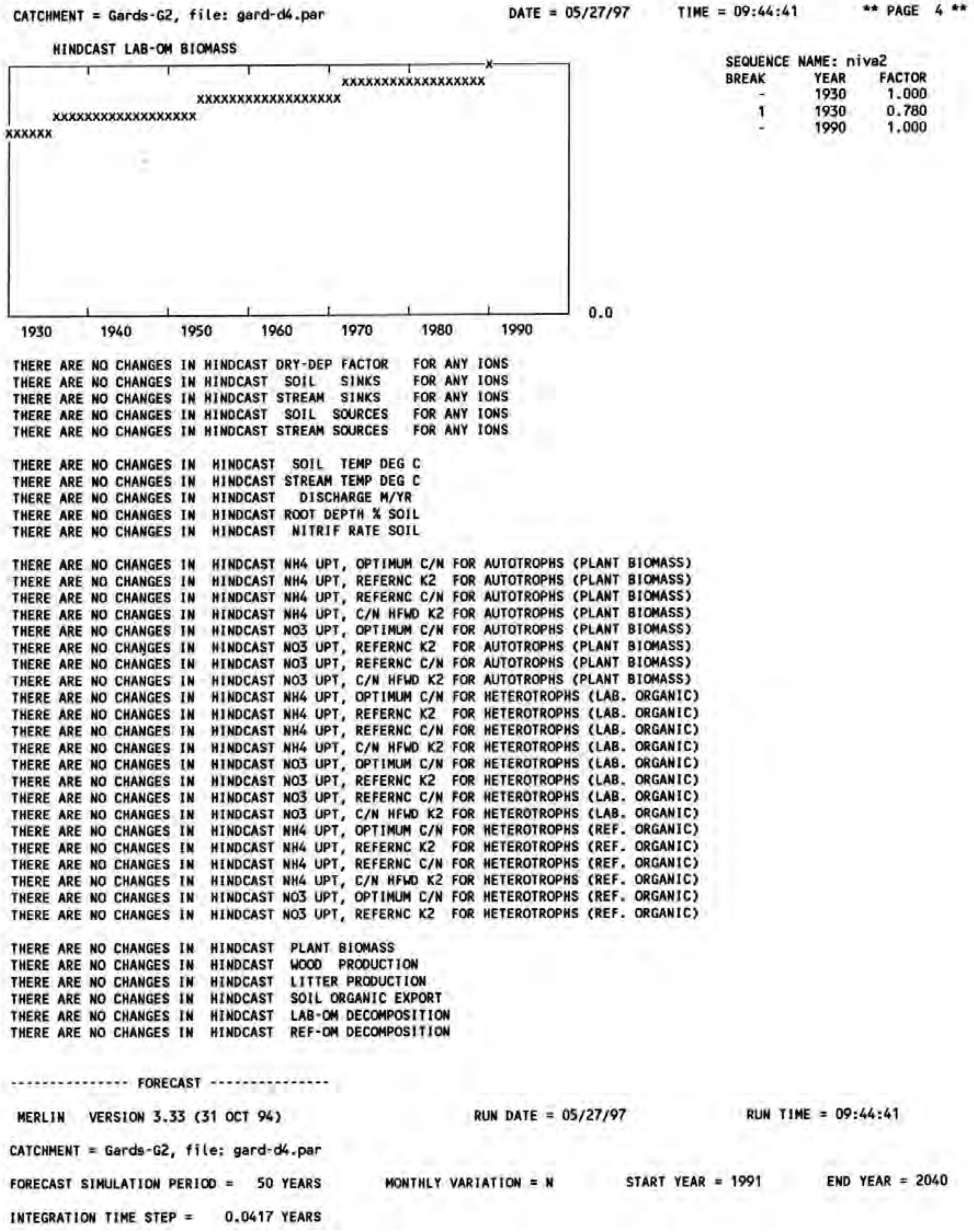


```
CATCHMENT = Gards-G2, file: gard-d4.par                    DATE = 05/27/97      TIME = 09:44:41        ** PAGE  2 **


--------------- HINDCAST ---------------

 MERLIN   VERSION 3.33 (31 OCT 94)                      RUN DATE = 05/27/97                  RUN TIME = 09:44:41

CATCHMENT = Gards-G2, file: gard-d4.par

HINDCAST SIMULATION PERIOD =    60 YEARS          MONTHLY VARIATION = N          START YEAR = 1930        END YEAR = 1990

INTEGRATION TIME STEP =     0.0417 YEARS

                                             ROUTING OF FLOW THROUGH THE CATCHMENT IS:

                                              F1 = % RUNOFF NOT CONTACTING TERRESTRIAL AREAS

                                                         --%-      -----------MM----------
                                                          F1      Q1     Q3     Q4     Q7
                                             ANNUAL AVE   0.      0.   464.   464.   464.


   MEAN ANNUAL DISCHARGE =       0.464 M/YR

   MEAN ANNUAL PRECIPITATION =       1.000 M/YR

                -------- REFERENCE YEAR 1990                       ------- BACKGROUND YEAR 1930
                 PRECIP CONC    DEPOSITION                          PRECIP CONC    DEPOSITION
                   (MEQ/M3)       FACTOR                              (MEQ/M3)       FACTOR

NH4                  42.0          1.0                                  6.5            1.0
NO3                  42.0          1.0                                  6.5            1.0

THE FOLLOWING CONDITIONS ARE SET FOR Gards-G2, file: gard-d4.par

   CONSTANT--------------------------STREAM          CONSTANT----------------------------SOIL
   RETENTION TIME (YR)                   0.00          SOIL DEPTH (M)                          0.50
   RELATIVE AREA (FRAC)                  0.00          POROSITY (FRAC)                         0.45
   MEAN DEPTH (M)                        0.00          BULK DENSITY (KG/M3)                 1200.00
                                                       NH4 MAX CAP (MEQ/KG)                    0.00
                                                       NH4 HLF SAT (MEQ/M3)                    0.00
                                                       NO3 MAX CAP (MEQ/KG)                    0.00
                                                       NO3 HLF SAT (MEQ/M3)                    0.00
                                                       PORE VOLUME (M)                         0.22
                                                       SOIL MASS (KG/M2)                     600.00

BIOLOGICAL PARAMETERS FOR NITROGEN ASSIMILATION

      AUTOTROPHS (PLANT BIOMASS)            HETEROTROPHS (LAB. ORGANIC)           HETEROTROPHS (REF. ORGANIC)
   NH4 UPT, OPTIMUM C/N      80.000     NH4 UPT, OPTIMUM C/N      35.000     NH4 UPT, OPTIMUM C/N      35.000
   NH4 UPT, REFERNC K2     1000.000     NH4 UPT, REFERNC K2     1000.000     NH4 UPT, REFERNC K2     1000.000
   NH4 UPT, REFERNC C/N      60.000     NH4 UPT, REFERNC C/N      20.000     NH4 UPT, REFERNC C/N      30.000
   NH4 UPT, C/N HFWD K2       0.200     NH4 UPT, C/N HFWD K2       1.700     NH4 UPT, C/N HFWD K2       0.500
   NO3 UPT, OPTIMUM C/N      80.000     NO3 UPT, OPTIMUM C/N      35.000     NO3 UPT, OPTIMUM C/N      35.000
   NO3 UPT, REFERNC K2     1000.000     NO3 UPT, REFERNC K2     1000.000     NO3 UPT, REFERNC K2     1000.000
   NO3 UPT, REFERNC C/N      60.000     NO3 UPT, REFERNC C/N      20.000     NO3 UPT, REFERNC C/N      30.000
   NO3 UPT, C/N HFWD K2       0.200     NO3 UPT, C/N HFWD K2       1.700     NO3 UPT, C/N HFWD K2       0.500
```

```
CATCHMENT = Gards-G2, file: gard-d4.par                       DATE = 05/27/97       TIME = 09:44:41        ** PAGE  3 **


C/N RATIOS FOR ORGANIC NITROGEN TRANSFERS

         C/N RATIOS (ORGANIC FLUXES)
    C/N FOR WOOD PRODUCT      335.000
    C/N FOR LITTER              0.000
    C/N FOR DECOMP LOM          0.000
    C/N FOR DECAY LOM           0.000
    C/N FOR DECOMP ROM          0.000
    C/N FOR ORGNC EXPORT        0.000

 (SETTING THE C/N FOR ANY FLUX = ZERO CAUSES THE PROGRAM TO USE THE C/N OF THE TOTAL SOURCE BIOMASS POOL TO CALCULATE N TRANSFER


            ----------------STREAM     -----------------SOIL
                   SOURCES                    SOURCES
              MEQ/M2/YR  MEQ/M2/YR        MEQ/M2/YR  MEQ/M2/YR
             BACKGROUND  REFERENCE       BACKGROUND  REFERENCE
NH4                 0.0        0.0              0.0        0.0
NO3                 0.0        0.0              0.0        0.0


            ----------------STREAM     -----------------SOIL
                    SINKS                      SINKS
              MEQ/M2/YR  MEQ/M2/YR        MEQ/M2/YR  MEQ/M2/YR
             BACKGROUND  REFERENCE       BACKGROUND  REFERENCE
NH4                 0.0        0.0              0.0        0.0
NO3                 0.0        0.0              0.0        0.0

  (NEGATIVE SINK RATES SET SINKS PROPORTIONAL TO EXTERNAL SOURCES)


              ---------STREAM     -----------------------------SOIL
                   TEMP DEG C     TEMP DEG C  ROOT DEP %  NITRF RATE
    ANNUAL AVE           12.0           12.0       100.0    1000.000


INITIAL CONDITIONS FOR CARBON AND NITROGEN POOLS

   INIT PLNT C (MOL/M2)       98.600     INIT LOM C (MOL/M2)       309.660     INIT ROM C (MOL/M2)        1308.000
   INIT PLNT N (MOL/M2)        1.500     INIT LOM N (MOL/M2)         7.500     INIT ROM N (MOL/M2)          40.700
   INIT PLNT C/N              65.733     INIT LOM C/N               41.288     INIT ROM C/N                 32.138

   INIT SOIL NH4 MEQ/M3        1.000     INIT SOIL NO3 MEQ/M3        1.000


              ----------------------------------------MOL-C/M2------------------------------------MOL-C/M2/YR
                  PLANT BIOMASS          LAB-OM BIOMASS          WOOD  PRODUCTION        LITTER PRODUCTION
    ANNUAL AVE               98.60000               397.00000                 3.55000                22.80000


              -------------------------------------MOL-C/M2/YR----------------------------------------------
                  SOIL ORGANIC EXPORT    LAB-OM DECOMPOSITION    REF-OM DECOMPOSITION
    ANNUAL AVE               0.35000                21.00000                 1.36000

 (NEGATIVE DECOMPOSITION RATES SET DECOMPOSITION PROPORTIONAL TO INPUTS TO THE POOL)

   HINDCAST WET DEPOSITION      USED FOR:  NH4  NO3
```



```
SEQUENCE NAME: from Dick
BREAK        YEAR     FACTOR
  -          1930      0.000
  1          1950      0.000
  2          1960      0.240
  3          1970      0.650
  4          1980      1.000
  -          1990      1.000
```



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CATCHMENT = Gards-G2, file: gard-d4.par              DATE = 05/27/97     TIME = 09:44:41        ** PAGE  4 **

     HINDCAST LAB-OM BIOMASS
 ---------------------------------------------------------------x-------           SEQUENCE NAME: niva2
|                                        xxxxxxxxxxxxxxxxxx     |                 BREAK     YEAR     FACTOR
|                          xxxxxxxxxxxxxxxxxx                   |                   -       1930      1.000
|    xxxxxxxxxxxxxxxxxx                                         |                   1       1930      0.780
xxxxxx                                                          |                   -       1990      1.000
|                                                               |
|                                                               |
|                                                               |
|                                                               |
|                                                               |
|                                                               |
 ----------------------------------------------------------------  0.0
 1930     1940     1950     1960     1970     1980     1990

THERE ARE NO CHANGES IN HINDCAST DRY-DEP FACTOR   FOR ANY IONS
THERE ARE NO CHANGES IN HINDCAST  SOIL   SINKS    FOR ANY IONS
THERE ARE NO CHANGES IN HINDCAST STREAM  SINKS    FOR ANY IONS
THERE ARE NO CHANGES IN HINDCAST  SOIL  SOURCES   FOR ANY IONS
THERE ARE NO CHANGES IN HINDCAST STREAM SOURCES   FOR ANY IONS

THERE ARE NO CHANGES IN  HINDCAST  SOIL  TEMP DEG C
THERE ARE NO CHANGES IN  HINDCAST STREAM TEMP DEG C
THERE ARE NO CHANGES IN  HINDCAST   DISCHARGE M/YR
THERE ARE NO CHANGES IN  HINDCAST ROOT DEPTH % SOIL
THERE ARE NO CHANGES IN  HINDCAST  NITRIF RATE SOIL

THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, OPTIMUM C/N FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, REFERNC K2  FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, REFERNC C/N FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, C/N HFWD K2 FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, OPTIMUM C/N FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, REFERNC K2  FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, REFERNC C/N FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, C/N HFWD K2 FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, OPTIMUM C/N FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, REFERNC K2  FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, REFERNC C/N FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, C/N HFWD K2 FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, OPTIMUM C/N FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, REFERNC K2  FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, REFERNC C/N FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, C/N HFWD K2 FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, OPTIMUM C/N FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, REFERNC K2  FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, REFERNC C/N FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, C/N HFWD K2 FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, OPTIMUM C/N FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, REFERNC K2  FOR HETEROTROPHS (REF. ORGANIC)

THERE ARE NO CHANGES IN  HINDCAST  PLANT BIOMASS
THERE ARE NO CHANGES IN  HINDCAST  WOOD  PRODUCTION
THERE ARE NO CHANGES IN  HINDCAST  LITTER PRODUCTION
THERE ARE NO CHANGES IN  HINDCAST  SOIL ORGANIC EXPORT
THERE ARE NO CHANGES IN  HINDCAST  LAB-OM DECOMPOSITION
THERE ARE NO CHANGES IN  HINDCAST  REF-OM DECOMPOSITION


--------------- FORECAST ---------------

 MERLIN   VERSION 3.33 (31 OCT 94)              RUN DATE = 05/27/97              RUN TIME = 09:44:41

CATCHMENT = Gards-G2, file: gard-d4.par

FORECAST SIMULATION PERIOD =   50 YEARS       MONTHLY VARIATION = N       START YEAR = 1991       END YEAR = 2040

INTEGRATION TIME STEP =    0.0417 YEARS
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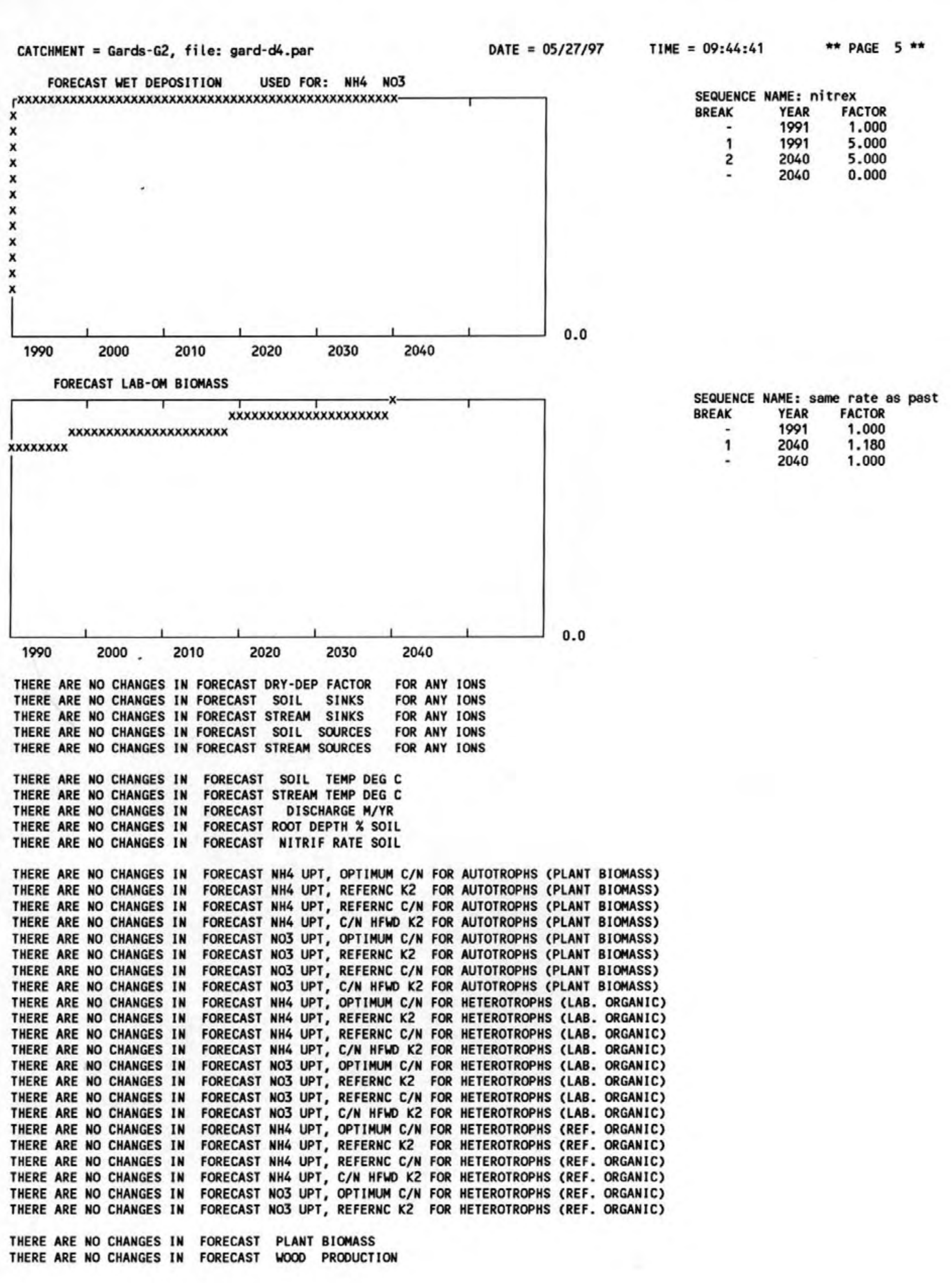

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CATCHMENT = Gards-G2, file: gard-d4.par                  DATE = 05/27/97     TIME = 09:44:41       ** PAGE  5 **

     FORECAST WET DEPOSITION      USED FOR:  NH4  NO3
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx                             SEQUENCE NAME: nitrex
x                                                                               BREAK      YEAR    FACTOR
x                                                                                 -        1991     1.000
x                                                                                 1        1991     5.000
x                                                                                 2        2040     5.000
x                                                                                 -        2040     0.000
x
x
x
x
x
x
x
                                                                  0.0
  1990      2000      2010      2020      2030      2040

      FORECAST LAB-OM BIOMASS
                                                  x                             SEQUENCE NAME: same rate as past
                             xxxxxxxxxxxxxxxxxxxxx                              BREAK      YEAR    FACTOR
        xxxxxxxxxxxxxxxxxxxxx                                                     -        1991     1.000
xxxxxxx                                                                           1        2040     1.180
                                                                                  -        2040     1.000

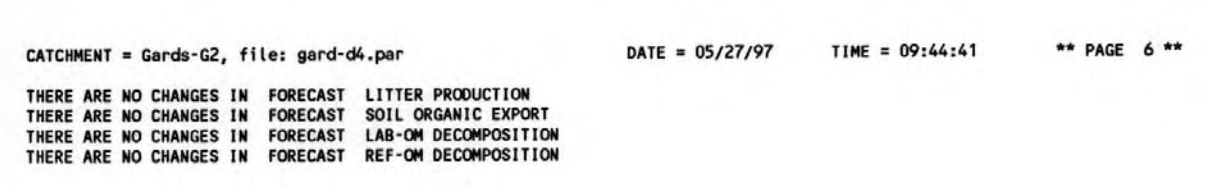
                                                                  0.0
  1990      2000      2010      2020      2030      2040

THERE ARE NO CHANGES IN FORECAST DRY-DEP FACTOR   FOR ANY IONS
THERE ARE NO CHANGES IN FORECAST  SOIL   SINKS    FOR ANY IONS
THERE ARE NO CHANGES IN FORECAST STREAM  SINKS    FOR ANY IONS
THERE ARE NO CHANGES IN FORECAST  SOIL  SOURCES   FOR ANY IONS
THERE ARE NO CHANGES IN FORECAST STREAM SOURCES   FOR ANY IONS

THERE ARE NO CHANGES IN  FORECAST  SOIL  TEMP DEG C
THERE ARE NO CHANGES IN  FORECAST STREAM TEMP DEG C
THERE ARE NO CHANGES IN  FORECAST   DISCHARGE M/YR
THERE ARE NO CHANGES IN  FORECAST ROOT DEPTH % SOIL
THERE ARE NO CHANGES IN  FORECAST  NITRIF RATE SOIL

THERE ARE NO CHANGES IN  FORECAST NH4 UPT, OPTIMUM C/N FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, REFERNC K2  FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, REFERNC C/N FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, C/N HFWD K2 FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, OPTIMUM C/N FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, REFERNC K2  FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, REFERNC C/N FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, C/N HFWD K2 FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, OPTIMUM C/N FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, REFERNC K2  FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, REFERNC C/N FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, C/N HFWD K2 FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, OPTIMUM C/N FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, REFERNC K2  FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, REFERNC C/N FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, C/N HFWD K2 FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, OPTIMUM C/N FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, REFERNC K2  FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, REFERNC C/N FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, C/N HFWD K2 FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, OPTIMUM C/N FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, REFERNC K2  FOR HETEROTROPHS (REF. ORGANIC)

THERE ARE NO CHANGES IN  FORECAST  PLANT BIOMASS
THERE ARE NO CHANGES IN  FORECAST  WOOD  PRODUCTION
```



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CATCHMENT = Gards-G2, file: gard-d4.par                    DATE = 05/27/97      TIME = 09:44:41        ** PAGE  6 **

THERE ARE NO CHANGES IN  FORECAST  LITTER PRODUCTION
THERE ARE NO CHANGES IN  FORECAST  SOIL ORGANIC EXPORT
THERE ARE NO CHANGES IN  FORECAST  LAB-OM DECOMPOSITION
THERE ARE NO CHANGES IN  FORECAST  REF-OM DECOMPOSITION
```

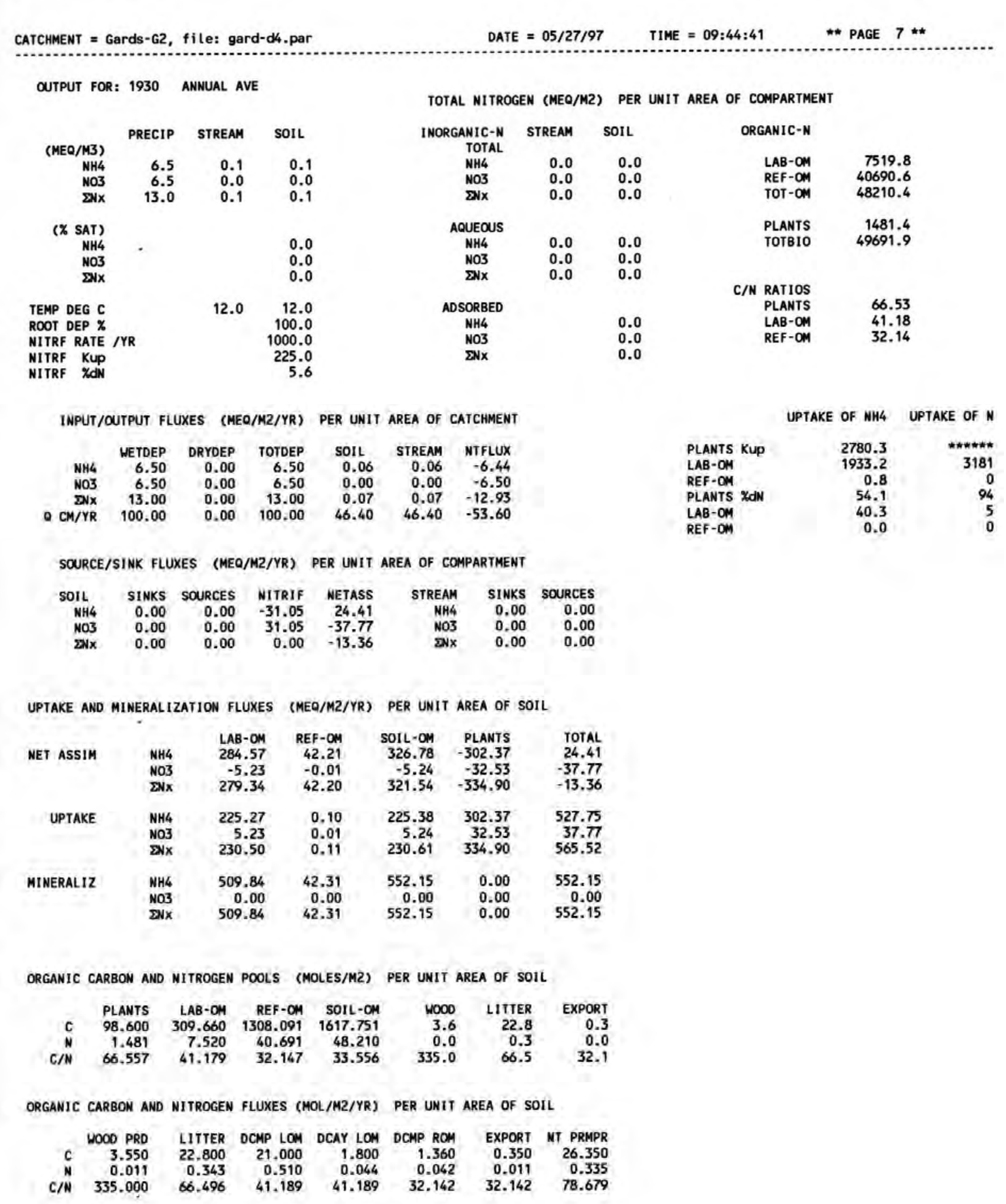

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CATCHMENT = Gards-G2, file: gard-d4.par                         DATE = 05/27/97      TIME = 09:44:41        ** PAGE  7 **
---------------------------------------------------------------------------------------------------------------------------

   OUTPUT FOR: 1930   ANNUAL AVE
                                                        TOTAL NITROGEN (MEQ/M2)  PER UNIT AREA OF COMPARTMENT

                PRECIP   STREAM     SOIL                 INORGANIC-N   STREAM    SOIL            ORGANIC-N
    (MEQ/M3)                                                 TOTAL
         NH4       6.5      0.1      0.1                     NH4          0.0     0.0              LAB-OM      7519.8
         NO3       6.5      0.0      0.0                     NO3          0.0     0.0              REF-OM     40690.6
         ΣNx      13.0      0.1      0.1                     ΣNx          0.0     0.0              TOT-OM     48210.4

     (% SAT)                                                AQUEOUS                                PLANTS      1481.4
         NH4                         0.0                     NH4          0.0     0.0              TOTBIO     49691.9
         NO3                         0.0                     NO3          0.0     0.0
         ΣNx                         0.0                     ΣNx          0.0     0.0
                                                                                                C/N RATIOS
  TEMP DEG C                12.0    12.0                   ADSORBED                                PLANTS       66.53
  ROOT DEP %                       100.0                     NH4                  0.0              LAB-OM       41.18
  NITRF RATE /YR                  1000.0                     NO3                  0.0              REF-OM       32.14
  NITRF  Kup                       225.0                     ΣNx                  0.0
  NITRF  %dN                         5.6

      INPUT/OUTPUT FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF CATCHMENT                                  UPTAKE OF NH4  UPTAKE OF N

             WETDEP   DRYDEP   TOTDEP     SOIL   STREAM   NTFLUX                    PLANTS Kup          2780.3       ******
        NH4    6.50     0.00     6.50     0.06     0.06    -6.44                    LAB-OM              1933.2         3181
        NO3    6.50     0.00     6.50     0.00     0.00    -6.50                    REF-OM                 0.8            0
        ΣNx   13.00     0.00    13.00     0.07     0.07   -12.93                    PLANTS %dN            54.1           94
   Q CM/YR  100.00     0.00   100.00    46.40    46.40   -53.60                    LAB-OM                40.3            5
                                                                                    REF-OM                 0.0            0

      SOURCE/SINK FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF COMPARTMENT

      SOIL     SINKS  SOURCES   NITRIF   NETASS      STREAM    SINKS  SOURCES
        NH4     0.00     0.00   -31.05    24.41         NH4     0.00     0.00
        NO3     0.00     0.00    31.05   -37.77         NO3     0.00     0.00
        ΣNx     0.00     0.00     0.00   -13.36         ΣNx     0.00     0.00


  UPTAKE AND MINERALIZATION FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF SOIL

                             LAB-OM     REF-OM      SOIL-OM    PLANTS        TOTAL
  NET ASSIM       NH4        284.57      42.21       326.78   -302.37        24.41
                  NO3         -5.23      -0.01        -5.24    -32.53       -37.77
                  ΣNx        279.34      42.20       321.54   -334.90       -13.36

     UPTAKE       NH4        225.27       0.10       225.38    302.37       527.75
                  NO3          5.23       0.01         5.24     32.53        37.77
                  ΣNx        230.50       0.11       230.61    334.90       565.52

  MINERALIZ       NH4        509.84      42.31       552.15      0.00       552.15
                  NO3          0.00       0.00         0.00      0.00         0.00
                  ΣNx        509.84      42.31       552.15      0.00       552.15


  ORGANIC CARBON AND NITROGEN POOLS  (MOLES/M2)  PER UNIT AREA OF SOIL

            PLANTS    LAB-OM     REF-OM    SOIL-OM        WOOD     LITTER     EXPORT
       C    98.600   309.660   1308.091   1617.751         3.6       22.8        0.3
       N     1.481     7.520     40.691     48.210         0.0        0.3        0.0
     C/N    66.557    41.179     32.147     33.556       335.0       66.5       32.1

  ORGANIC CARBON AND NITROGEN FLUXES (MOL/M2/YR)  PER UNIT AREA OF SOIL

          WOOD PRD    LITTER   DCMP LOM   DCAY LOM   DCMP ROM     EXPORT   NT PRMPR
       C     3.550    22.800     21.000      1.800      1.360      0.350     26.350
       N     0.011     0.343      0.510      0.044      0.042      0.011      0.335
     C/N   335.000    66.496     41.189     41.189     32.142     32.142     78.679
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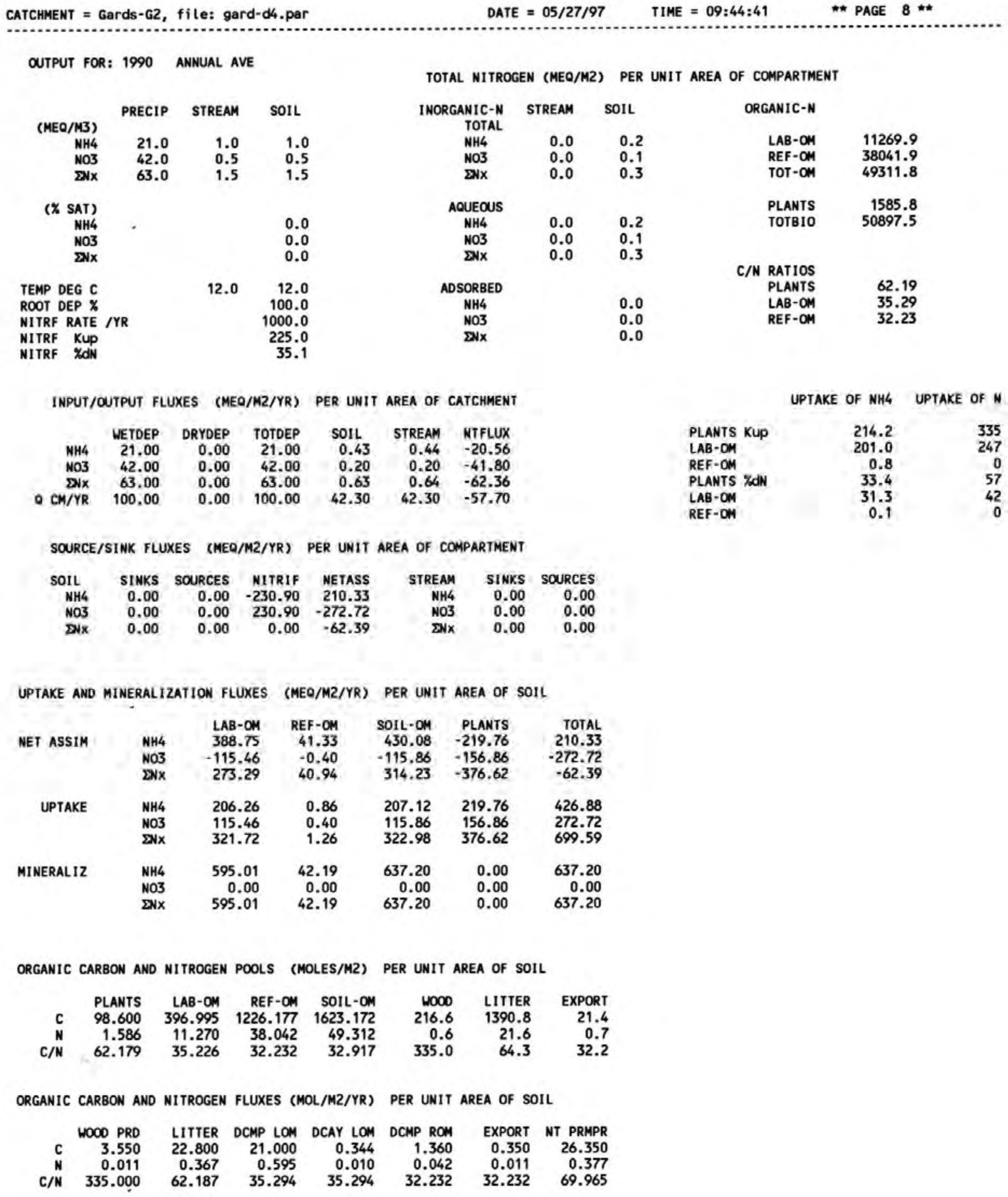

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  OUTPUT FOR: 1990   ANNUAL AVE
                                                         TOTAL NITROGEN (MEQ/M2)  PER UNIT AREA OF COMPARTMENT

               PRECIP   STREAM    SOIL                   INORGANIC-N  STREAM    SOIL           ORGANIC-N
   (MEQ/M3)                                                  TOTAL
        NH4     21.0       1.0     1.0                       NH4        0.0      0.2              LAB-OM      11269.9
        NO3     42.0       0.5     0.5                       NO3        0.0      0.1              REF-OM      38041.9
        ΣNx     63.0       1.5     1.5                       ΣNx        0.0      0.3              TOT-OM      49311.8

    (% SAT)                                                AQUEOUS                                PLANTS       1585.8
        NH4                        0.0                       NH4        0.0      0.2              TOTBIO      50897.5
        NO3                        0.0                       NO3        0.0      0.1
        ΣNx                        0.0                       ΣNx        0.0      0.3
                                                                                               C/N RATIOS
 TEMP DEG C               12.0    12.0                     ADSORBED                               PLANTS        62.19
 ROOT DEP %                      100.0                       NH4                 0.0              LAB-OM        35.29
 NITRF RATE /YR                 1000.0                       NO3                 0.0              REF-OM        32.23
 NITRF  Kup                      225.0                       ΣNx                 0.0
 NITRF  %dN                       35.1

    INPUT/OUTPUT FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF CATCHMENT                              UPTAKE OF NH4  UPTAKE OF N

          WETDEP   DRYDEP   TOTDEP    SOIL   STREAM   NTFLUX                         PLANTS Kup         214.2          335
    NH4    21.00     0.00    21.00    0.43     0.44   -20.56                         LAB-OM             201.0          247
    NO3    42.00     0.00    42.00    0.20     0.20   -41.80                         REF-OM               0.8            0
    ΣNx    63.00     0.00    63.00    0.63     0.64   -62.36                         PLANTS %dN          33.4           57
 Q CM/YR  100.00     0.00   100.00   42.30    42.30   -57.70                         LAB-OM              31.3           42
                                                                                     REF-OM               0.1            0

    SOURCE/SINK FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF COMPARTMENT

    SOIL      SINKS  SOURCES   NITRIF   NETASS    STREAM   SINKS  SOURCES
      NH4      0.00     0.00  -230.90   210.33       NH4    0.00     0.00
      NO3      0.00     0.00   230.90  -272.72       NO3    0.00     0.00
      ΣNx      0.00     0.00     0.00   -62.39       ΣNx    0.00     0.00


 UPTAKE AND MINERALIZATION FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF SOIL

                          LAB-OM    REF-OM      SOIL-OM    PLANTS      TOTAL
 NET ASSIM       NH4      388.75     41.33       430.08   -219.76     210.33
                 NO3     -115.46     -0.40      -115.86   -156.86    -272.72
                 ΣNx      273.29     40.94       314.23   -376.62     -62.39

    UPTAKE       NH4      206.26      0.86       207.12    219.76     426.88
                 NO3      115.46      0.40       115.86    156.86     272.72
                 ΣNx      321.72      1.26       322.98    376.62     699.59

 MINERALIZ       NH4      595.01     42.19       637.20      0.00     637.20
                 NO3        0.00      0.00         0.00      0.00       0.00
                 ΣNx      595.01     42.19       637.20      0.00     637.20


 ORGANIC CARBON AND NITROGEN POOLS  (MOLES/M2)  PER UNIT AREA OF SOIL

           PLANTS    LAB-OM    REF-OM   SOIL-OM       WOOD    LITTER    EXPORT
      C    98.600   396.995  1226.177  1623.172      216.6    1390.8      21.4
      N     1.586    11.270    38.042    49.312        0.6      21.6       0.7
    C/N    62.179    35.226    32.232    32.917      335.0      64.3      32.2

 ORGANIC CARBON AND NITROGEN FLUXES (MOL/M2/YR)  PER UNIT AREA OF SOIL

         WOOD PRD    LITTER  DCMP LOM  DCAY LOM  DCMP ROM    EXPORT  NT PRMPR
      C     3.550    22.800    21.000     0.344     1.360     0.350    26.350
      N     0.011     0.367     0.595     0.010     0.042     0.011     0.377
    C/N   335.000    62.187    35.294    35.294    32.232    32.232    69.965
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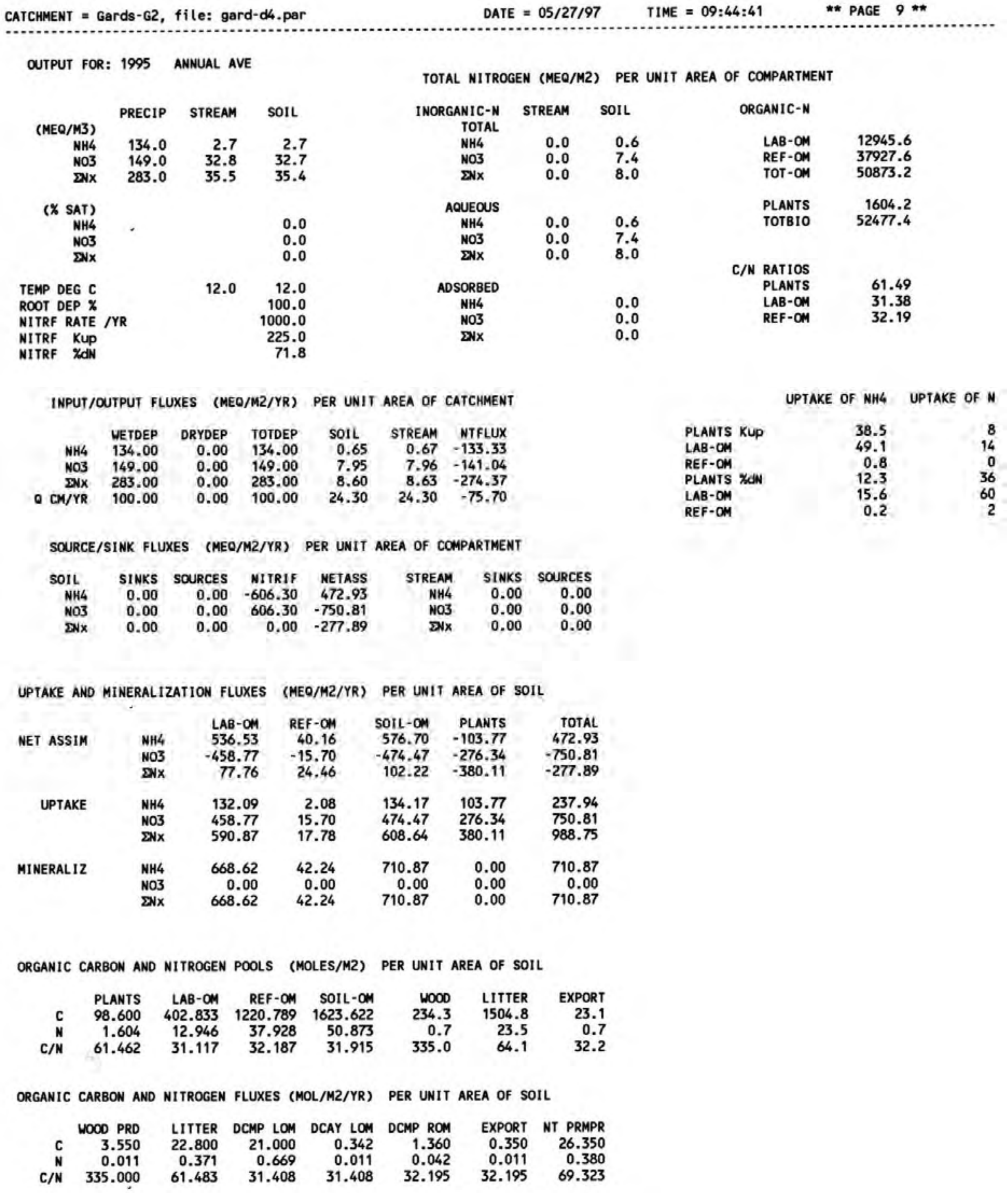

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   OUTPUT FOR: 1995   ANNUAL AVE
                                                      TOTAL NITROGEN (MEQ/M2)  PER UNIT AREA OF COMPARTMENT

               PRECIP   STREAM    SOIL               INORGANIC-N   STREAM    SOIL              ORGANIC-N
    (MEQ/M3)                                               TOTAL
         NH4    134.0      2.7      2.7                    NH4        0.0      0.6                LAB-OM      12945.6
         NO3    149.0     32.8     32.7                    NO3        0.0      7.4                REF-OM      37927.6
         ΣNx    283.0     35.5     35.4                    ΣNx        0.0      8.0                TOT-OM      50873.2

     (% SAT)                                             AQUEOUS                                  PLANTS       1604.2
         NH4                        0.0                    NH4        0.0      0.6                TOTBIO      52477.4
         NO3                        0.0                    NO3        0.0      7.4
         ΣNx                        0.0                    ΣNx        0.0      8.0
                                                                                              C/N RATIOS
  TEMP DEG C              12.0     12.0                 ADSORBED                                  PLANTS        61.49
  ROOT DEP %                      100.0                    NH4                 0.0                LAB-OM        31.38
  NITRF RATE /YR                 1000.0                    NO3                 0.0                REF-OM        32.19
  NITRF  Kup                      225.0                    ΣNx                 0.0
  NITRF  %dN                       71.8

      INPUT/OUTPUT FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF CATCHMENT                                   UPTAKE OF NH4   UPTAKE OF N

              WETDEP   DRYDEP   TOTDEP    SOIL    STREAM   NTFLUX                       PLANTS Kup            38.5             8
        NH4   134.00     0.00   134.00     0.65     0.67  -133.33                       LAB-OM                49.1            14
        NO3   149.00     0.00   149.00     7.95     7.96  -141.04                       REF-OM                 0.8             0
        ΣNx   283.00     0.00   283.00     8.60     8.63  -274.37                       PLANTS %dN            12.3            36
    Q CM/YR   100.00     0.00   100.00    24.30    24.30   -75.70                       LAB-OM                15.6            60
                                                                                        REF-OM                 0.2             2

      SOURCE/SINK FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF COMPARTMENT

      SOIL     SINKS  SOURCES   NITRIF   NETASS     STREAM    SINKS  SOURCES
        NH4     0.00     0.00  -606.30   472.93        NH4     0.00     0.00
        NO3     0.00     0.00   606.30  -750.81        NO3     0.00     0.00
        ΣNx     0.00     0.00     0.00  -277.89        ΣNx     0.00     0.00


  UPTAKE AND MINERALIZATION FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF SOIL

                            LAB-OM   REF-OM     SOIL-OM    PLANTS       TOTAL
  NET ASSIM       NH4       536.53    40.16      576.70   -103.77      472.93
                  NO3      -458.77   -15.70     -474.47   -276.34     -750.81
                  ΣNx        77.76    24.46      102.22   -380.11     -277.89

     UPTAKE       NH4       132.09     2.08      134.17    103.77      237.94
                  NO3       458.77    15.70      474.47    276.34      750.81
                  ΣNx       590.87    17.78      608.64    380.11      988.75

  MINERALIZ       NH4       668.62    42.24      710.87      0.00      710.87
                  NO3         0.00     0.00        0.00      0.00        0.00
                  ΣNx       668.62    42.24      710.87      0.00      710.87


  ORGANIC CARBON AND NITROGEN POOLS  (MOLES/M2)  PER UNIT AREA OF SOIL

            PLANTS    LAB-OM    REF-OM   SOIL-OM      WOOD    LITTER    EXPORT
      C     98.600   402.833  1220.789  1623.622     234.3    1504.8      23.1
      N      1.604    12.946    37.928    50.873       0.7      23.5       0.7
    C/N     61.462    31.117    32.187    31.915     335.0      64.1      32.2

  ORGANIC CARBON AND NITROGEN FLUXES (MOL/M2/YR)  PER UNIT AREA OF SOIL

          WOOD PRD    LITTER  DCMP LOM  DCAY LOM  DCMP ROM    EXPORT  NT PRMPR
      C      3.550    22.800    21.000     0.342     1.360     0.350    26.350
      N      0.011     0.371     0.669     0.011     0.042     0.011     0.380
    C/N    335.000    61.483    31.408    31.408    32.195    32.195    69.323
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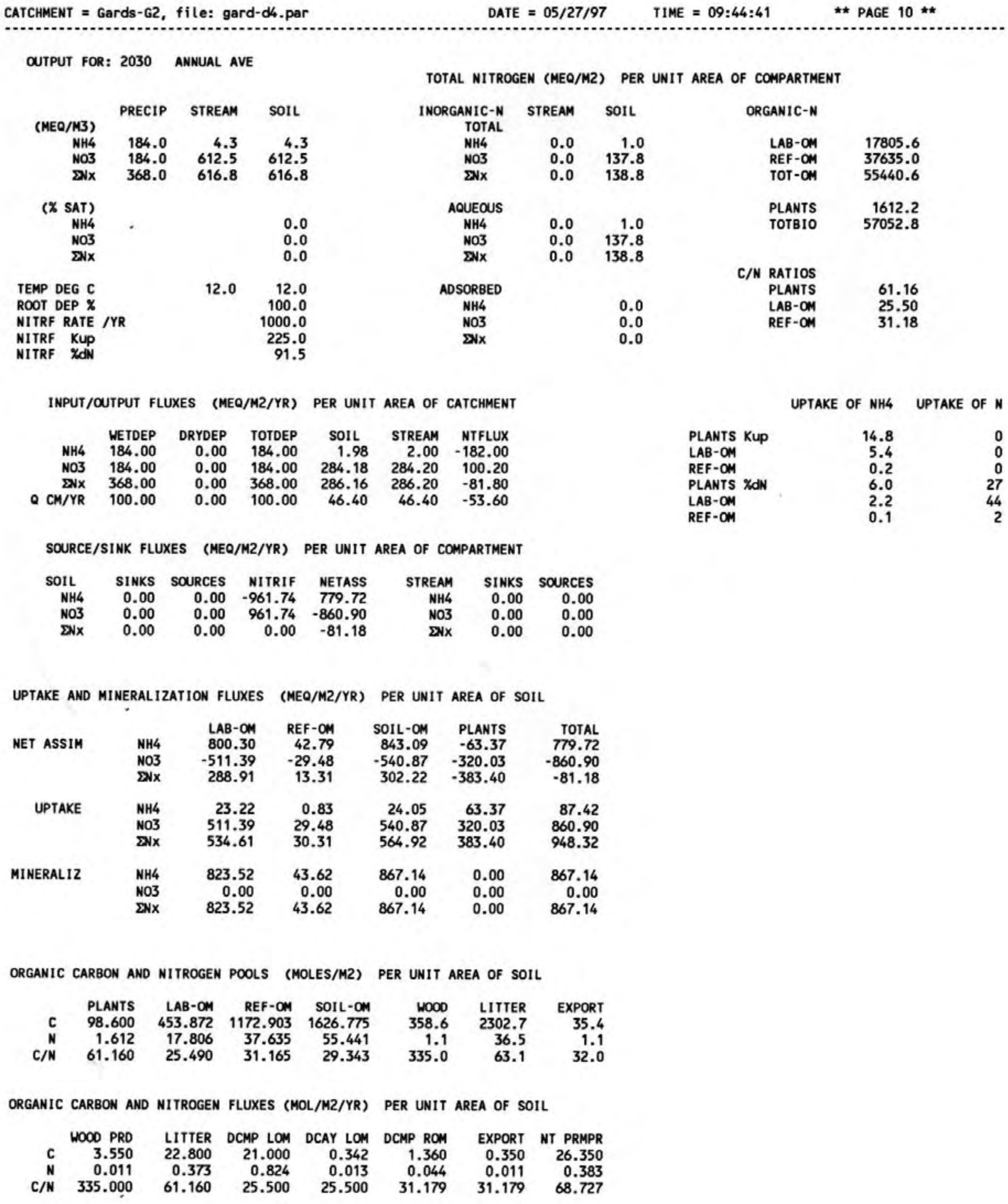

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  OUTPUT FOR: 2030   ANNUAL AVE
                                                   TOTAL NITROGEN (MEQ/M2)  PER UNIT AREA OF COMPARTMENT

            PRECIP   STREAM    SOIL              INORGANIC-N  STREAM    SOIL              ORGANIC-N
   (MEQ/M3)                                         TOTAL
        NH4  184.0     4.3      4.3                  NH4       0.0      1.0                  LAB-OM     17805.6
        NO3  184.0   612.5    612.5                  NO3       0.0    137.8                  REF-OM     37635.0
        ΣNx  368.0   616.8    616.8                  ΣNx       0.0    138.8                  TOT-OM     55440.6

    (% SAT)                                        AQUEOUS                                   PLANTS      1612.2
        NH4     .                 0.0                NH4       0.0      1.0                  TOTBIO     57052.8
        NO3                       0.0                NO3       0.0    137.8
        ΣNx                       0.0                ΣNx       0.0    138.8
                                                                                          C/N RATIOS
 TEMP DEG C            12.0      12.0             ADSORBED                                   PLANTS       61.16
 ROOT DEP %                     100.0                NH4              0.0                    LAB-OM       25.50
 NITRF RATE /YR                1000.0                NO3              0.0                    REF-OM       31.18
 NITRF  Kup                     225.0                ΣNx              0.0
 NITRF  %dN                      91.5

    INPUT/OUTPUT FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF CATCHMENT                          UPTAKE OF NH4  UPTAKE OF N

          WETDEP   DRYDEP   TOTDEP    SOIL    STREAM   NTFLUX                   PLANTS Kup         14.8            0
     NH4  184.00     0.00   184.00    1.98     2.00   -182.00                   LAB-OM              5.4            0
     NO3  184.00     0.00   184.00  284.18   284.20    100.20                   REF-OM              0.2            0
     ΣNx  368.00     0.00   368.00  286.16   286.20    -81.80                   PLANTS %dN          6.0           27
  Q CM/YR 100.00     0.00   100.00   46.40    46.40    -53.60                   LAB-OM              2.2           44
                                                                                REF-OM              0.1            2
    SOURCE/SINK FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF COMPARTMENT

    SOIL     SINKS  SOURCES   NITRIF    NETASS     STREAM    SINKS  SOURCES
      NH4     0.00     0.00  -961.74    779.72       NH4      0.00     0.00
      NO3     0.00     0.00   961.74   -860.90       NO3      0.00     0.00
      ΣNx     0.00     0.00     0.00    -81.18       ΣNx      0.00     0.00


 UPTAKE AND MINERALIZATION FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF SOIL

                        LAB-OM     REF-OM     SOIL-OM    PLANTS      TOTAL
 NET ASSIM       NH4    800.30      42.79      843.09    -63.37     779.72
                 NO3   -511.39     -29.48     -540.87   -320.03    -860.90
                 ΣNx    288.91      13.31      302.22   -383.40     -81.18

    UPTAKE       NH4     23.22       0.83       24.05     63.37      87.42
                 NO3    511.39      29.48      540.87    320.03     860.90
                 ΣNx    534.61      30.31      564.92    383.40     948.32

 MINERALIZ       NH4    823.52      43.62      867.14      0.00     867.14
                 NO3      0.00       0.00        0.00      0.00       0.00
                 ΣNx    823.52      43.62      867.14      0.00     867.14


 ORGANIC CARBON AND NITROGEN POOLS  (MOLES/M2)  PER UNIT AREA OF SOIL

          PLANTS    LAB-OM    REF-OM   SOIL-OM      WOOD    LITTER    EXPORT
      C   98.600   453.872  1172.903  1626.775     358.6    2302.7      35.4
      N    1.612    17.806    37.635    55.441       1.1      36.5       1.1
    C/N   61.160    25.490    31.165    29.343     335.0      63.1      32.0

 ORGANIC CARBON AND NITROGEN FLUXES (MOL/M2/YR)  PER UNIT AREA OF SOIL

        WOOD PRD    LITTER  DCMP LOM  DCAY LOM  DCMP ROM    EXPORT  NT PRMPR
      C    3.550    22.800    21.000     0.342     1.360     0.350    26.350
      N    0.011     0.373     0.824     0.013     0.044     0.011     0.383
    C/N  335.000    61.160    25.500    25.500    31.179    31.179    68.727
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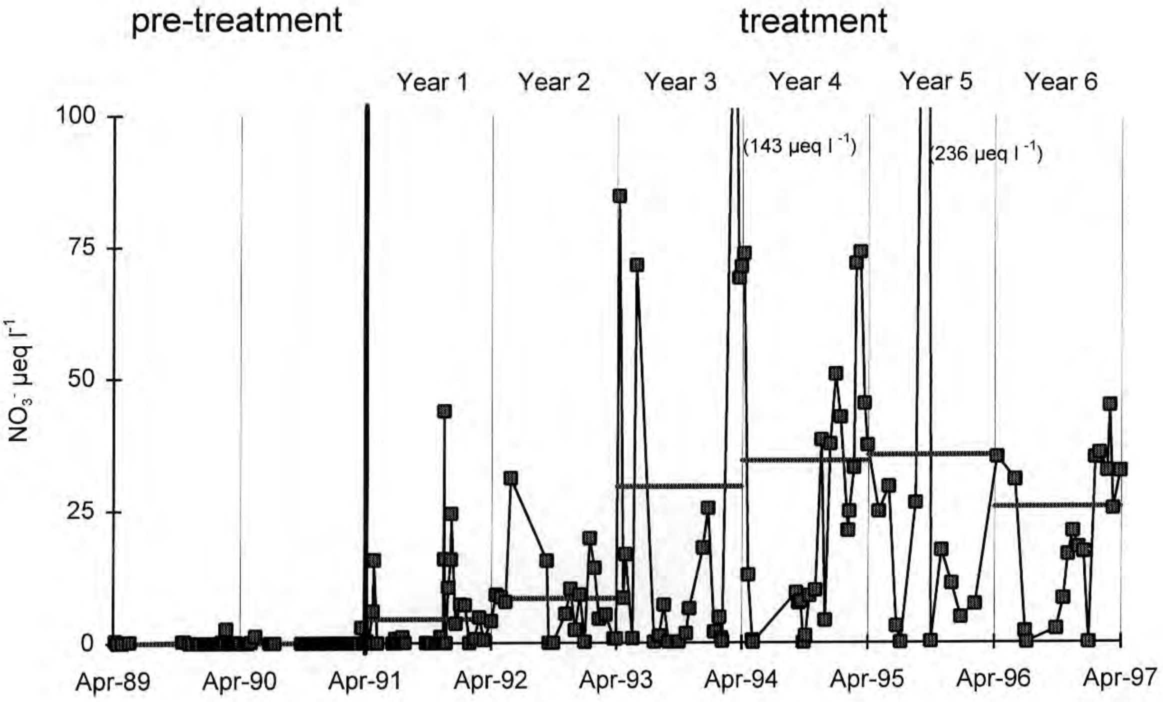
pre-treatment
treatment
Year 1
Year 2
Year 3
Year 4
Year 5
Year 6
100
75
50
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0
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(143 µeq l^{-1})
(236 µeq l^{-1})
Apr-89
Apr-90
Apr-91
Apr-92
Apr-93
Apr-94
Apr-95
Apr-96
Apr-97

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