COMPUTER SIMULATION MODELS OF THE PORCUPINE CARIBOU HERD: I. ENERGY

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Canadian Wildlife Service

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ABSTRACT

The energy relations of the Porcupine caribou herd are presented in a computer simulation model. In this model input variables (diet, biomass of major forage types, nutrient content of forage, proportion of the day spent feeding, etc.) are simulated for 15 life cycle periods for the herd. Using a simplified rumen function model, with an hour iteration period, we predict daily metabolizable energy intake for an individual caribou. The present model is one of three models, ENERGY, GROWTH and HARVEST, that were developed at the request of the Porcupine Caribou Technical Committee. The models run on IBM compatable microcomputers that have graphics capability. The supervisor program, Microsimcon, is incorporated in each model and assists in exercising the models.

RÉSUMÉ

Les relations énérgetiques du troupeau de caribous Porcupine sont présentées dans un modèle de simulation par ordinateur. Dans ce modèle, les variables d'entrée (régime alimentaire, biomasse des principaux types de fourrage, teneur en éléments nutrifs du fourrage, proportion de la journée consacrée à l'alimentation, etc.) sont simulées pour 15 périodes du cycle vital, pour le troupeau. En utilisant un modèle simplifié de la fonction du rumen, comportant une période itérative d'une heure, nous pouvons prévoir l'apport quotidien d'énergie métabolisable pour un caribou individuel. Ce modèle fait partie des trois modèles (ÉNERGIE, CROISSANCE et RÉCOLTE) qui ont été mis au point à la demande du Comité technique de cariou Porcupine. Les modèles sont utilisables sur les micro-ordinateurs ayant une compatibilité IBM et une capacité inforgraphique. Le programme superviseur, Microsimcon, est incorporé dans chaque modèle et facilite l'application et la vérification des modèles.

INTRODUCTION

Research and monitoring of the Porcupine caribou herd have been conducted almost continuously since the early 1970's. As more information is gathered it becomes increasingly difficult to integrate and apply that information to complex questions regarding effects on the herd from human activities and developments. The Porcupine Caribou Technical Committee, therefore, requested that individuals involved in research and management of the herd develop computer simulation models to aid in evaluating the present data, to help guide future research, and to provide some insights into the potential impact of alternate development scenarios. To this end the Canadian Wildlife Service contracted a group from the Faculty of Forestry, University of British Columbia, to help facilitate a number of workshops and to program the agreed upon models. From those discussions, three models were proposed. By order of increasing iteration time these models are: an ENERGY model which simulates the energetic relations of an individual and predicts the metabolizable energy intake (MEI) on a daily basis; a GROWTH model that incorporates the resultant MEI and projects the weight gain and loss throughout the year; and a HARVEST model that simulates the demographics of the herd over a number of years.

The models incorporate a simulation supervisor program that was adapted to microcomputers (Microsimcon), allowing efficient and user-friendly access while exercising the models. All coding is done in Basic using a "Quick Basic" compiler. All users of the models will require an IBM compatible computer with graphics capability.

This publication represents Version 1 of the models. Updates, executable files and other information on the model are available from D.E. Russell, Canadian Wildlife Service, Whitehorse.

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Caribou Energy Model

PURPOSE

The ENERGY model asks the question: how do changes in activity budgets, forage quality, and forage quantity affect the energy intake of a female caribou? In particular, it is designed to predict effects of specific environmental conditions on metabolizable energy intake (MEI). Several relations describing how environmental conditions affect forage intake, or how forage intake effects metabolizable energy, are poorly understood. The energy model thus serves a second broad purpose: it exposes gaps in understanding and helps formulate hypotheses.

Specific objectives of the model are to:

1) show effects of different environmental conditions (as reflected by activity budgets, forage quality, and forage quantity) on MEI by female caribou;

2) evaluate effects of different levels of insect harassment on MEI; and

3) evaluate changing of winter severity, as reflected by snow depth, on MEI.

GENERAL DESCRIPTION

The model has two major parts. First it calculates food intake in specific environments, then it simulates functioning of the rumen of a female caribou and her digestive kinetics to predict metabolizable energy from forage intake (Figure 1).

Calculating forage intake, the model's first step, requires specification of the environment in which the caribou is feeding. That environment is determined by three habitat scenarios: the basic, lowland, and upland/foothill scenarios. The basic scenario determines diet characteristics assuming the caribou is living in its usual habitat and calving grounds; the lowlands scenario assumes the caribou calves in an area dominated by wet sedge meadow; the uplands/foothills scenario assumes the calving grounds are restricted to upland/foothill habitat, an area where bulls usually concentrate.

Forage intake in each environment is governed by three broad constraints:

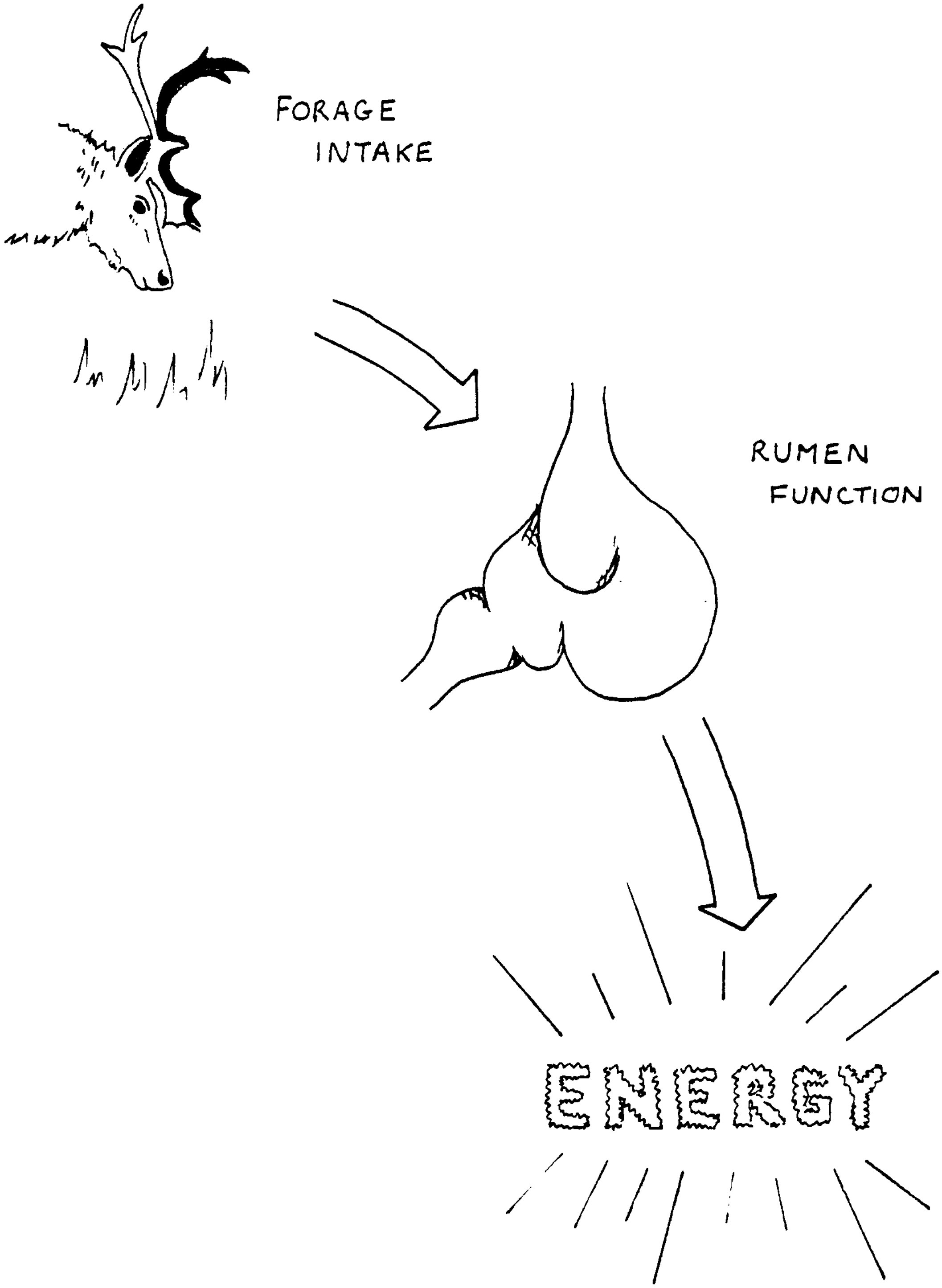

Figure 1. Generalized flowchart of the ENERGY model.

1) availability of forage and time available for the caribou to ingest that forage (logistic constraint);
2) capacity of the rumen (rumen constraint); and
3) energetic needs of the caribou (metabolic constraint).

In the model four simple logistic factors determine the maximum amount of forage a caribou can ingest: available biomass of each forage group, proportion of the diet made up by each forage group, the rate at which the caribou encounters each forage group, and time spent eating.

Rumen capacity may limit forage intake below that intake determined by logistic factors. For example, a caribou foraging on poorly digestible forage may fill its rumen so that it can not ingest more forage until digestion has reduced forage in the rumen.

Energetic needs of the caribou are determined from empirical daily activity budgets with an allowance for maximum growth and fattening. If the caribou meets its maximum energetic requirement while foraging, then it does not ingest any more forage.

The model begins by calculating the logistic constraint and compares this intake with those intakes calculated by the other two constraints. The model assumes intake is governed by the logistic constraint unless overridden by one of the other two constraints. Food intake calculated using the logistic constraint is digested to determine rumen fill and energy intake. Rumen fill is then compared to rumen capacity to determine if food intake should be limited by rumen capacity. Energy intake is compared to energy requirements to see if food intake should be limited by the metabolic constraint. For the metabolic constraint to operate, food intake under the logistic constraint must yield more energy than the caribou needs. The minimum constraint, whether logistic, rumen capacity or metabolic is specified as forage intake.

Because factors controlling the logistic constraint operate on a daily basis, that constraint is calculated daily. To accommodate for different rates of digestion and passage, the model calculates the rumen capacity and metabolic constraints on food intake on an hourly basis (sensu Hudson and White 1986).

During the second step of the model, forage intake specified by the minimum constraint is digested to determine MEI.

STEPPING THROUGH THE MODEL

A. Timestep

Because the three constraints limiting food intake are calculated for different time periods, the model operates on both a daily and an hourly time step.

B. Model Inputs

1) Seasons

The model has the potential to vary the beginning and end of each season by Julian day. Currently, the model uses 15 seasons (Table 1).

2) Activity budgets

Activity budgets are set empirically for each of the fifteen seasons and three habitat scenarios. Seasonal activity budget data are linearly interpolated to provide daily values. Activity budgets are provided for high and low insect harassment levels and high and low snow accumulation. Activity budgets (App. 1; tables A1-6.) are estimated as proportions by five activities: foraging, lying, standing, walking, running, and eating intensity. When caribou are foraging in winter, not all of the time spent foraging is spent actually consuming food. Often, the caribou must paw through snow to uncover forage buried beneath. The model accounts for time spent pawing and eating while foraging by separating the foraging activity into two components: 1) eating intensity, which is the proportion of the foraging period spent consuming food, and 2) pawing intensity, which is the proportion of the foraging period spent cratering for forage. Ideally, eating intensity and pawing intensity would add to one. Foraging bouts, however, include time standing while cratering. This time standing is already forms part of 'time spent standing', thus eating intensity and pawing intensity do not add to one.

To generate forage intake, the model uses only foraging time and eating intensity from the activity budget data to estimate the time spent eating. Total activity costs are not determined from the data but are specified in the set file (see App. 1).

3) Forage characteristics

The model does not simulate food selection. Diets are driven empirically each season for the three habitat scenarios and both mild and severe winter conditions. For each scenario, dietary components have been estimated as proportions (0.00-1.00) of nine plant groups: moss, lichen, mushrooms, horsetails, graminoids, deciduous shrubs, evergreen shrubs, forbs, and dead material. Dietary components for each season and scenario include: gross energy, digestible energy, total nitrogen, digestible nitrogen, neutral detergent fiber, and available biomass. Dietary components are determined from empirical fecal data corrected for differential digestibilities (App 1, Tables B,C, and D1-6.). Seasonal forage data are linearly interpolated between seasons to provide daily values.

The basic scenario utilizes dietary components determined from data collected from usual seasonal habitats and calving grounds of the Porcupine Caribou herd. The lowlands scenario assumes the caribou is in an area dominated by wet sedge meadow during the calving period. This scenario uses dietary components based on corrected empirical fecal data collected from Prudhoe Bay, an area of wet sedge meadow. The uplands/foothills scenario assumes the caribou is in upland areas during calving. It uses dietary components determined from corrected fecal data collected from the usual area

Table 1. Description of the 15 Seasons

Season	Dates	Characteristics
1. Mid winter	11 January - 20 February	snow cover increasing; very cold
2. Late winter	21 February - 31 March	snow cover peaking
3. Spring	1 - 30 April	snow cover decreasing
4. Spring migration	1 May - 19 May (but variable)	80-100% snow cover; rotting.
5. Pre-calving	20 May - 1 June	10-50% snow cover disappearing rapidly; cottongrass in bud
6. Calving	1 - 10 June	0-10% snow cover; cottongrass in full flower; willow leaves in bud
7. Post-calving	11 - 20 June	cottongrass past flowering; willow leaves unfolding
8. Movement	21 - 31 June	willow in leaf; biomass increasing rapidly
9. Early summer	1 - 15 July	biomass peaking; mosquitos peaking
10. Mid summer	16 July - 7 August	biomass at peak; mosquitos past peak, and oestrid flies peaking
11. Late summer	8 August - 7 September	vascular forage quality declining
12. Fall migration	8 September - 7 October	early snow storms
13. Rut	8 - 31 October	snow but melting
14. Late fall	1 - 30 November	beginning of winter snow cover
15. Early winter	1 December - 20 January	snow cover shallow; shortest day length; very cold

of bull caribou concentrations during the calving period. Both the lowland and the upland/foothill scenarios involve changes to the basic scenario only during the seasons around calving (seasons 5-7); diets for each scenario are identical after June 20.

C. Calculated Variables

The following sections describe calculations of the logistic, rumen capacity, and metabolic constraints on food intake. After the constraints are calculated, food intake is specified and digested to produce MEI.

1) Calculating logistically possible forage intake

The first task of the model is to determine the potential forage intake and resulting MEI based solely on the logistic constraints imposed by available biomass, the rate at which the caribou finds the forage (plant encounter rates), known grazing time, and known dietary composition.

(a) determining biomass available and forage intake:

Available forage biomass data were recorded as the mean available biomass ($g \cdot$dry matter/m^2) plus two standard deviations for each habitat considered in each season. This allowance considers that caribou within a vegetative community select higher biomass microsites but still restricts biomass within the confines of that community. Available forage biomass is converted in the model from live weight dry matter (g/m^2) to dry matter biomass (kg/ha) for use in equations calculating forage intake. Available dry matter biomass influences the rate at which caribou encounter their forage. Together, available biomass and known plant encounter rates for each forage group determine potential forage intake.

The amount of forage that can be ingested per minute for each forage group is calculated from plant encounter rates and available biomass as:

```
FIP(PLANT)=AR(PLANT)*FB(PLANT)/(1.+AR(PLANT)
                              *FB(PLANT)/PCMAX(PLANT))          (1)
```

where FIP is potential forage intake (g/min) of each plant group,
AR is the effective rate of search and takes into account the area searched per unit time and the probability of caribou recognizing and successfully ingesting forage in that area (ha/min).
FB is available forage biomass (kg/ha dry weight) for each plant group, and
PCMAX is the maximum consumption rate (g/min) for each plant group and used in the equations predicting plant group intake rates.

Equation 1 has the form of Holling's disc equation (Holling 1965).

Potential forage intake of each forage group is constrained by the amount of time actually spent eating and the proportion of each plant group making up the daily diet. Although forage intake under the logistic constraint is calculated only once a day, forage intake is described as forage intake per hour. The proportion of each day spent eating is calculated from the proportion of the day spent foraging and the eating intensity (which indicates the proportion of the foraging time actually spent eating). The proportion of the day spent eating is assigned to each hour, which results in every hour having the same proportion of time spent eating. Actual forage intake during each hour, as determined only by logistic constraints, is calculated as:

FIP(PLANT)=FIP(PLANT)*DPDP(PLANT)*60.*GT (2)

where FIP is actual forage intake for each plant group (g/h),
DPDP is the proportion that each plant group makes up of the daily diet (0.0-1.0), and
GT is the proportion of time spent eating and is calculated as eating intensity multiplied by the proportion of the hour spent foraging.

(b) logistic constraint

Total forage intake each hour (TFI (g/h)) over all plant groups is calculated by summing the forage intake of each plant group (FIP). This is forage intake determined by the logistic constraint.

2) Calculating the rumen constraint on forage intake

To determine if forage intake is limited by rumen capacity, the amount of fill in the rumen must be calculated. The amount of fill in the rumen depends on the amount of forage ingested and rates of digestion and passage that forage is exposed to.

(a) Digesting forage:

Ingested forage is composed of both digestible and non-digestible material. Both components are subject to different rates of digestion and passage. To determine the digestible component of forage intake, actual forage intake (FIP) for each hour and each plant group is multiplied by its dry matter digestibility:

DFI(PLANT)=FIP(PLANT)*DPDIG(PLANT) (3)

where DFI is Digestible forage intake (g/h),
DPDIG is dry matter digestibility by plant group (proportion), and
FIP is the actual forage intake for each plant group (g/h).

In the model, the digestible portion of forage intake is composed of nitrogen intake, cell content intake, and digestible cell wall intake. Partitioning digestible forage intake into cell wall, cell content, and nitrogen components allows the assumption of constant digestibilities for these components. Using broad forage components is a simplification for programming (Figure 2), obviously the caribou does not partition its forage in that manner.

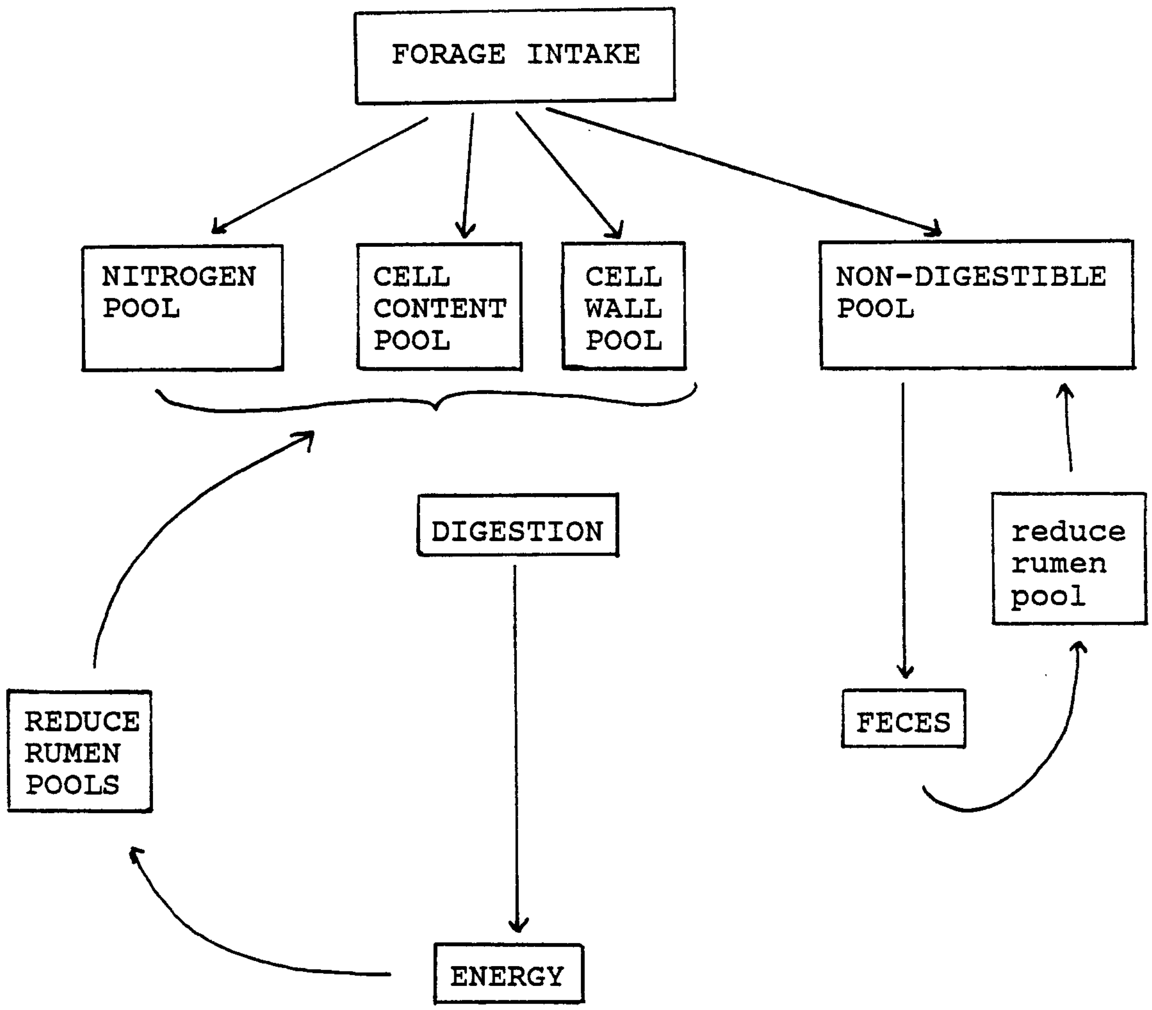

Figure 2. Structure of the ENERGY model

Nitrogen intake is determined simply from the percent digestible nitrogen available from each plant group. Currently the model only accumulates nitrogen intake. Nitrogen could influence digestive kinetics in later versions of the model.

Nitrogen intake is calculated as:

NITRO(PLANT)=DFI(PLANT)*DPNIT(PLANT)/100 (4)

where NITRO is digestible nitrogen intake for each plant group (g/h),
DFI is digestible forage intake for each plant group (g/h), and
DPNIT is the percent nitrogen content for each plant (%).

Cell content intake is calculated as:

CCI(PLANT)=FIP(PLANT)*(1.-DPCWAL(PLANT)) (5)

where CCI is cell content intake (g/h),
FIP is actual forage intake for each plant group (g/h), and
DPCWAL is the proportion of cell wall for each plant group and is calculated from neutral detergent fibre analysis.

Digestible cell wall intake is calculated as the remaining component of digestible forage intake:

CWI(PLANT)=FIP(PLANT)-NONDIGFI(PLANT)-CCI(PLANT) (6)

where CWI is digestible cell wall intake for each plant group (g/h),
FIP is actual food intake for each plant group (g/h),
CCI is the cell content intake for each plant group (g), and

NONDIGFI(PLANT) =FIP(PLANT)*(1.-DPDIG(PLANT));

Where NONDIGFI is non-digestible forage intake for each plant group (g/h),
FIP is the actual forage intake for each plant group (g/h), and
DPDIG is the plant group digestibility (proportion).

Digestible forage intake values are added to pools of digestible forage already existing in the rumen: the nitrogen pool (NITRO), the cell wall pool (CELWAL) and the cell content pool (CELCON).

(b) Non-digestible material:

The non-digestible forage intake of each plant group is calculated from the digestibility of each plant group:

NONDIGFI(PLANT)=FIP(PLANT)*(1-DPDIG(PLANT)) (7)

where NONDIGFI is non-digestible forage intake (g/h)

The passage rate of non-digestible material of each plant group from the rumen is calculated as a function of digestibility:

KNDIG(PLANT)=1./(50.-50.*DPDIG(PLANT)) (8)

where KNDIG is the passage rate of non-digestible material for each plant group (proportion/h), and
DPDIG is the digestibility of each plant group (proportion).

Together, non-digestible forage intake and passage rates determine the amount of non-digestible material in the rumen for each plant group:

NRFP(PLANT)=(NRFP(PLANT)+NONDIGFI(PLANT))
*(1-KNDIG(PLANT)) (9)

where NRFP is the non-digestible material in the rumen for each plant group (g),
NONDIGFI(plant) is the non-digestible intake for each plant group (g/h), and
KNDIG is the passage rate of non-digestible material for each plant group (proportion/h).

The total non-digestible pool (TNRF(g)), combined over all plant groups, is calculated as the sum of the non-digestible rumen pools for each plant group (NRFP(g)).

The amount of feces output is calculated as the amount of non-digestible material in the rumen multiplied by its passage rate:

FECES(PLANT)=(NRFP(PLANT)+NONDIGFI)*KNDIG(PLANT) (10)

where FECES is the output of non-digestible material of each plant group from the rumen (g/h),
NRFP is the non-digestible rumen pool for each plant group (g),
NONDIGFI is the non-digestible food intake for each plant group (g/h), and
KNDIG is the rate of passage of non-digestible material from the rumen for each plant group (proportion/h).

The amount of feces is accumulated to provide a daily total and can be used to check if passage rates are reasonable.

(c) Reducing rumen pools:

After digesting forage in the rumen, the rumen pools must be reduced by the amount of each pool digested. The cell content pool is reduced by:

CELCON=CELCON*(1.-K(CCON)) (11)

where CELCON is the pool of cell content in the rumen each hour (g), and
K(CCON) is the proportion of cell contents digested in an hour (digestion rate), set initially to 0.3

The cell wall pool is reduced by:

CELWAL=CELWAL*(1.-K(CWAL)) (12)

where CELWAL is the pool of cell wall in the rumen each hour (g), and
K(CWAL) is the digestion rate of cell contents, set initially to 0.009.

The total rumen fill, therefore is the sum of reduced pools of digestible forage and non-digestible material:

RFILL=CELCON+CELWAL+TNRF (13)

where RFILL is the amount of forage in the rumen each hour (g),
CELCON is the amount of the cell content in the rumen each hour (g),
CELWAL is the amount of the cell wall in the rumen each hour (g), and
TNRF is the amount of non-digestible material in the rumen each hour (g).

(d) rumen capacity constraint

The rumen capacity constraint is calculated as the difference between rumen capacity and rumen fill:

CONST(3)=RCAP-RFILL (14)

where CONST(3) is forage intake determined by the physical constraint of reaching rumen capacity (g),
RCAP is the capacity of the rumen and is set at 3600 g, and
RFILL is the amount of forage in the rumen (g).

3) Calculating the metabolic constraint on forage intake:

The metabolic constraint on food intake is calculated by comparing the potential energy obtained from the caribou's diet to the caribou's maximum energy requirements. Those requirements include costs of activity, growth, and fattening. If the diet supplies more energy than the caribou requires then food intake is limited so that it provides only as much energy as the caribou can use.

(a) Calculating energy yield from forage intake

The first step in calculating the metabolic constraint is determining energy yield from food intake. Every hour, digestible forage in the rumen from previous hours' foraging and forage ingested in the current hour is digested to yield energy. Forage not digested in the hour constitutes the basis of the subsequent hour's rumen pool.

Metabolizable energy from the pool of cell contents in the rumen is calculated as:

CCNRG=CELCON*K(CCON)*DPNRG(CCON)*MEC(CCON) (15)

where CCNRG is the energy obtained from cell contents (kJ/h),
CELCON is the cell content rumen pool (g),
K(CCON) is the digestion rate of cell contents (0.30/h),
DPNRG(CCON) is the digestible energy associated with cell contents (kJ/g), and
MEC(CCON) is the proportion of digestible energy of cell contents that can be metabolized.

Metabolizable energy obtained from the pool of cell wall material in the rumen is calculated as:

CWNRG=CELWAL*K(CWAL)*DPNRG(CWAL)*MEC(CWAL) (16)

where CWNRG is the energy obtained from the cell wall (kJ/h),
CELWAL is the amount of digestible cell wall material in the rumen each hour (g),
K(CWAL) is the digestion rate of cell wall (0.009/h),
DPNRG(CWAL) is the digestible energy associated with the cell wall (kJ/g), and
MEC(CWAL) is the proportion of digestible energy of cell wall that can be metabolized.

Total metabolizable energy for a day is calculated by accumulating hourly energy obtained from cell contents and cell wall over twenty-four hours.

Hourly energy intake is calculated as:

MEI=CCNRG+CWNRG (17)

where MEI is daily metabolizable energy intake (kJ),
CCNRG is the total energy from cell contents (kJ/h), and
CWNRG is the total energy from cell wall (kJ/h).

Daily MEI is simply the sum of each hour's MEI

(daily) MEI= MEI

(b) Calculating energy required to meet all costs

The second step in calculating the metabolic constraint is determining how much energy is required to meet all activity and growth costs. That required energy is calculated from seasonal activity budgets and fattening and growth requirements and is expressed as:

HACOST=ACTCST*WT75/24 (18)

where HACOST is the hourly energy requirement of all activities, including growth and fattening (kJ/kg),
ACTCST is the daily energy requirement for all activities, growth, and fattening ($kJ/kg^{0.75}$) which varies seasonally, and
WT75 is the caribou's metabolic weight.

(c) metabolic constraint

The energy required to meet all activity and growth costs requires a specific forage intake. That food intake, the metabolic constraint, is computed as the difference between the energy required for activities and the energy supplied by the rumen pool, divided by the amount of energy available from each gram of forage ingested. Thus, the metabolic constraint is calculated as:

CONST(1)=(HACOST-TER)/KJPG (19)

where CONST(1) is the food intake determined by the metabolic constraint (g),
HACOST is the energetic requirement of all activities (kJ),
TER is total energy from rumen pool before adding this hour's forage intake, and
KJPG is the energy yielded per gram of ingested forage (kJ/g).

The energy yielded per gram from ingested forage is expressed as the energy obtained from food intake in the hour (MEI-TER (kJ/h)), divided by forage intake in the hour (TFI(g)):

KJPG=((MEI-TER)/TFI) (20)

where KJPG is the energy (kJ/g) obtained from each gram of food intake,
MEI is the metabolizable energy calculated in the first hour from logistic food intake (kJ/h),
TFI is total food intake (g/h), and
TER is the total energy obtained from the rumen pool before adding forage ingested in the current hour (kJ/h).

TER=CCNRG*(1.-K(CCON))+CWNRG*(1.-K(CWAL))

where TER is the total energy from the rumen pool (kJ/h),
CCNRG is the energy obtained from cell contents (kJ/h),

K(CCON) is the digestion rate of cell contents (proportion),
CWNRG is the energy obtained from cell wall (kJ/h), and
K(CWAL) is the digestibility of cell wall (proportion).

4) Choosing which constraint operates on food intake:

The model compares each of the constraints on forage intake and selects the smallest one. That minimum constraint, whether logistic, physical, or metabolic, is the one that specifies food intake. Actual food intake as determined by the minimum constraint is used to recalculate digestive kinetics and produce metabolizable energy intake. Obviously, if the logistic constraint is operating then there is no need to recalculate the digestive kinetics. The constraint operating on food intake can change rapidly, thus constraints are allowed to change on an hourly basis in the model.

WEAKNESSES OF THE ENERGY MODEL:

The ENERGY model is still in a process of development, and thus has aspects that need improvement. We have identified a few of the more important weaknesses; detailed sensitivity analysis will undoubtedly reveal more.

The first weakness is the lack of nitrogen dynamics in the rumen. Currently, the model simply accumulates nitrogen on the basis of the percent of nitrogen in the diet. Other sources of nitrogen, besides dietary nitrogen, contribute to the nitrogen pool in the rumen. Those sources include nitrogen from endogenous protein and nitrogen from recycled urea. Nitrogen from all of the above sources entering the lower tract of the rumen is subject to competitive rates of digestion and passage. Those rates of digestion and passage have not been modelled. The efficiency of nitrogen digestion in the rumen will greatly impact the nitrogen available for maintenance and growth of lean tissue. It is known that nitrogen is an important substrate for microbes and at low levels may limit the rate of rumen fermentation. The effect of low levels of nitrogen on the rate of rumen fermentation has not been modelled.

Currently, rumen turnover time is dependent on the passage rates of the cell content pool, cell wall pool, and non-digestible pool. Those digestion rate or passage rates are based on "best guesses". The rate of digestion of cell wall pool appears to limit food intake in summer when high cell wall content builds up in the rumen, stopping further food intake and lowering metabolizable energy intake. Passage rates of non-digestible material from the rumen is presently a function of "1.-digestibility". Passage rates need to be verified and tested. The model is very sensitive to changes in the digestibilities of each forage group.

There is no consideration given to effect of caribou density on available biomass of forage species. Available forage is not decreased by caribou foraging. The model deals only with the energy acquisition of a single typical female caribou.

The model assumes that cell wall and cell content yield constant energy. Forage quality is determined only by the relative amounts of cell content and cell wall material. Energy derived from cell wall is the same for live forage as it is for dead forage. Similarly, energy derived from cell wall in winter is the same as for summer; presently, there is no seasonal variation in energy yielded from cell wall or cell content material.

The model does not simulate the effects of particle size on digestion. Particle size likely influences rumen turnover time and the relative rates of digestion of cell content and cell wall material.

The structure of the model reveals an additional weakness. Because activity budgets are driven empirically, the amount of time grazing is known. If that grazing time is altered because of encountering a rumen size constraint or metabolic constraint, then the grazing time in the model no longer matches the grazing time recorded in the activity budget. That difference implies that either activity budgets or forage characteristics are measured imperfectly, or that there are faulty relationships in the model.

References:

Holling, C.S. 1965. The functional response of predators to prey density and its role in mimicry and population regulations. Mem. Entomol. Soc. Canada. 45:1-60.

Hudson, R.J. and R.G. White. 1985. Computer simulation of energy budgets. pp. 216-286 in R.J. Hudson and R.G. White (eds.), Bioenergetics of Wild Herbivores. Boca Raton, Florida. CRC press. 314 pp.

APPENDIX 1

Operation

The following is a description of the operation of the ENERGY model. All the variables used in the program are described in App. 2. Interactive graphics will not be discussed; that part of the program is detailed in PC_SIMULATOR (Hovey 1988). The ENERGY model requires one set file and four data files.

The set file contains the following fifteen statements:

Statement	Description
K(1..2)	This array contains the digestion rates for cell content (1) and cell wall (2), described as the proportion of material in the rumen digested each hour.
NRFP(1...10)	Non-digestible material in the rumen for each of the ten plant groups (see table D1. for plant group definitions).
DPNRG(1...2)	Daily values of digestible energy for each plant group (kJ/g)
SDAY(1-8)	The midpoint, in Julien days for each the first eight seasons (see table 1 of (THE ENERGY MODEL for season definitions).
SDAY(9-15)	The midpoint, in Julien days for each of the last 7 seasons.
AR(1...10)	The area searched and probability of encountering and ingesting each plant group (ha/min).
PCMAX(1...10)	The maximum possible rate of consumption for a caribou foraging on each of the ten plant groups (g/min).
MEC(1...2)	The factors converting digestible energy of cell content (1) and cell wall (2) to metabolizable energy, respectively.
ACTCST	Total cost of all activities, growth, and fattening, on a metabolic weight basis ($kJ/kg^{0.75}$).
RCAP	The capacity of the rumen (g).
RFILL	Amount of forage in the rumen (g).
CELCON	Amount of cell contents in the rumen (g).
CELWAL	Amount of cell wall in the rumen (g).

WEIGHT	Weight of the female caribou (kg).
TIMESTOP	The iteration at which the simulation is to be interrupted.

The ENERGY model also uses the following four data files:

Data File Name	Description
1a) ACTHIHI.DAT	Activity budgets for high insect harassment and severe winters.
1b) ACTHILO.DAT	Activity budgets for high insect harassment and mild winters.
1c) ACTLOHI.DAT	Activity budgets for low insect harassment and severe winters.
1d) ACTLOLO.DAT	Activity budgets for low insect harassment and mild winters.
1e) HARASHI.DAT	Activity budgets for high, prolonged insect harassment and severe winter.
1f) HARASLO.DAT	Activity budgets for high, prolonged insect harassment and mild winters.
2) DIG.DAT	Plant group digestibility data
3) NDF.DAT	Plant group neutral detergent fiber data
4a) FORHI.BAS	Diet proportions, available biomass, and nitrogen for the Basic scenario in mild winters when caribou move to areas of deep snow
4b) FORHI.UPL	Diet proportions, available biomass, and nitrogen for the Upland secenario in mild winters when caribou move to areas of deep snow
4c) FORHI.LOW	Diet proportions, available biomass, and nitrogen for the Lowland secenario in mild winters when caribou move to areas of deep snow
4d) FORLO.BAS	Diet proportions, available biomass, and nitrogen for the Basic secenario in usual winters
4e) FORLO.UPL	Diet proportions, available biomass, and nitrogen for the Upland secenario in usual winters
4f) FORLO.LOW	Diet proportions, available biomass, and nitrogen for the Lowland scenario in usual winters

The above data file names are existing data file names. The user can give data files any valid DOS file names. Examples data files are provided in Tables A.-E. of this appendix. Appendix 2. contains The variable list for the ENERGY model.

Table A1. Example activity budgets for low insect harrassment and low snow years

Activities as Proportions

		a[1]	b	c	d	e	f	g
	1[2]	0.55	0.29	0.05	0.10	0.01	0.83	0.09
	2	0.46	0.43	0.04	0.07	0.00	0.93	0.03
	3	0.44	0.33	0.02	0.21	0.00	0.96	0.02
	4	0.44	0.33	0.02	0.21	0.00	0.96	0.00
	5	0.58	0.20	0.01	0.21	0.00	0.97	0.00
S	6	0.54	0.34	0.01	0.10	0.01	0.95	0.00
e	7	0.54	0.37	0.01	0.07	0.01	0.98	0.00
a	8	0.38	0.30	0.01	0.30	0.01	0.98	0.00
s	9	0.48	0.09	0.18	0.18	0.07	0.84	0.00
o	10	0.37	0.49	0.04	0.09	0.01	0.84	0.00
n	11	0.52	0.17	0.15	0.12	0.04	0.84	0.00
s	12	0.46	0.24	0.06	0.23	0.02	0.84	0.00
	13	0.41	0.28	0.08	0.21	0.02	0.84	0.00
	14	0.46	0.24	0.06	0.23	0.01	0.84	0.00
	15	0.59	0.21	0.06	0.13	0.01	0.86	0.09

[1] Activities: a=proportion of time spent foraging,
b=proportion of time spent lying,
c=proportion of time spent standing,
d=proportion of time spent walking
e=proportion of time spent running,
f=eating intensity (proportion of foraging period actually spent eating,
g=pawing intensity (proportion of foraging period spent cratering.

[2] See Table 1 of THE ENERGY MODEL for season definitions

Table A2. Example activity budgets for low insect harrassment and high snow years

Activities by Proportions

Seasons		a[1]	b	c	d	e	f	g
	1[2]	0.48	0.40	0.05	0.08	0.00	0.74	0.23
	2	0.45	0.47	0.05	0.03	0.00	0.60	0.36
	3	0.49	0.45	0.02	0.04	0.00	0.94	0.06
	4	0.44	0.33	0.02	0.21	0.00	0.96	0.00
	5	0.58	0.20	0.01	0.21	0.00	0.97	0.00
	6	0.54	0.34	0.01	0.10	0.01	0.95	0.00
	7	0.54	0.37	0.01	0.07	0.01	0.98	0.00
	8	0.38	0.30	0.01	0.30	0.01	0.98	0.00
	9	0.48	0.09	0.18	0.18	0.07	0.84	0.00
	10	0.37	0.49	0.04	0.09	0.01	0.84	0.00
	11	0.52	0.17	0.15	0.12	0.04	0.84	0.00
	12	0.46	0.24	0.06	0.23	0.02	0.84	0.00
	13	0.41	0.28	0.08	0.21	0.02	0.84	0.00
	14	0.46	0.24	0.06	0.23	0.01	0.84	0.00
	15	0.53	0.26	0.05	0.16	0.00	0.73	0.23

[1] Activities: a=proportion of time spent foraging,
b=proportion of time spent lying,
c=proportion of time spent standing,
d=proportion of time spent walking
e=proportion of time spent running,
f=eating intensity (proportion of foraging period actually spent eating,
g=pawing intensity (proportion of foraging period spent cratering.

[2] See Table 1 of THE ENERGY MODEL for season definitions

Table A3. Example activity budgets for high Insect harrassment and low snow years

Activities as Proportions

Seasons		a[1]	b	c	d	e	f	g
	1[2]	0.55	0.29	0.05	0.10	0.01	0.83	0.09
	2	0.46	0.43	0.04	0.07	0.00	0.93	0.03
	3	0.44	0.33	0.02	0.21	0.00	0.96	0.02
	4	0.44	0.33	0.02	0.21	0.00	0.96	0.00
	5	0.58	0.20	0.01	0.21	0.00	0.97	0.00
	6	0.54	0.34	0.01	0.10	0.01	0.95	0.00
	7	0.54	0.37	0.01	0.07	0.01	0.98	0.00
	8	0.38	0.30	0.01	0.30	0.01	0.98	0.00
	9	0.28	0.17	0.32	0.15	0.08	0.84	0.00
	10	0.23	0.13	0.27	0.25	0.12	0.84	0.00
	11	0.52	0.17	0.15	0.12	0.04	0.84	0.00
	12	0.46	0.24	0.06	0.23	0.02	0.84	0.00
	13	0.41	0.28	0.08	0.21	0.02	0.84	0.00
	14	0.46	0.24	0.06	0.23	0.01	0.84	0.00
	15	0.59	0.21	0.06	0.13	0.01	0.86	0.09

[1] Activities: a=proportion of time spent foraging,
b=proportion of time spent lying,
c=proportion of time spent standing,
d=proportion of time spent walking
e=proportion of time spent running,
f=eating intensity (proportion of foraging period actually spent eating,
g=pawing intensity (proportion of foraging period spent cratering.

[2] See Table 1 of THE ENERGY MODEL for season definitions

Table A4. Example activity budgets for high insect harrassment and high snow years

		Activity as Proportions						
		a[1]	b	c	d	e	f	g
	1[2]	0.48	0.40	0.05	0.08	0.00	0.74	0.23
	2	0.45	0.47	0.05	0.03	0.00	0.60	0.36
	3	0.49	0.45	0.02	0.04	0.00	0.94	0.06
	4	0.44	0.33	0.02	0.21	0.00	0.96	0.00
	5	0.58	0.20	0.01	0.21	0.00	0.97	0.00
S	6	0.54	0.34	0.01	0.10	0.01	0.95	0.00
e	7	0.54	0.37	0.01	0.07	0.01	0.98	0.00
a	8	0.38	0.30	0.01	0.30	0.01	0.98	0.00
s	9	0.28	0.17	0.32	0.15	0.08	0.84	0.00
o	10	0.23	0.13	0.27	0.25	0.12	0.84	0.00
n	11	0.52	0.17	0.15	0.12	0.04	0.84	0.00
s	12	0.46	0.24	0.06	0.23	0.02	0.84	0.00
	13	0.41	0.28	0.08	0.21	0.02	0.84	0.00
	14	0.46	0.24	0.06	0.23	0.01	0.84	0.00
	15	0.53	0.26	0.05	0.16	0.00	0.73	0.23

[1] Activities: a=proportion of time spent foraging,
b=proportion of time spent lying,
c=proportion of time spent standing,
d=proportion of time spent walking
e=proportion of time spent running,
f=eating intensity (proportion of foraging period actually spent eating,
g=pawing intensity (proportion of foraging period spent cratering.

[2] See Table 1 of THE ENERGY MODEL for season definitions

Table A5. Activity Budgets for Prolonged, High Insect Harrassment and Low Snow Years

Activities by Proportions

Seasons		a[1]	b	c	d	e	f	g
	1[2]	0.55	0.29	0.05	0.10	0.01	0.83	0.09
	2	0.46	0.43	0.04	0.07	0.00	0.93	0.03
	3	0.44	0.33	0.02	0.21	0.00	0.96	0.02
	4	0.44	0.33	0.02	0.21	0.00	0.96	0.00
S	5	0.25	0.15	0.28	0.25	0.07	0.84	0.00
e	6	0.25	0.20	0.28	0.20	0.07	0.84	0.00
a	7	0.25	0.20	0.28	0.20	0.07	0.84	0.00
s	8	0.23	0.13	0.27	0.30	0.07	0.84	0.00
o	9	0.28	0.17	0.32	0.15	0.08	0.84	0.00
n	10	0.23	0.13	0.27	0.25	0.12	0.84	0.00
s	11	0.52	0.17	0.15	0.12	0.04	0.84	0.00
	12	0.46	0.24	0.06	0.23	0.02	0.84	0.00
	13	0.41	0.28	0.08	0.21	0.02	0.84	0.00
	14	0.46	0.24	0.06	0.23	0.01	0.84	0.00
	15	0.59	0.21	0.06	0.13	0.01	0.86	0.09

[1] Activities: a=proportion of time spent foraging,
b=proportion of time spent lying,
c=proportion of time spent standing,
d=proportion of time spent walking
e=proportion of time spent running,
f=eating intensity (proportion of foraging period actually spent eating,
g=pawing intensity (proportion of foraging period spent cratering.

[2] See Table 1 of THE ENERGY MODEL for season definitions

Table A6. Activity Budgets for Prolonged, High Insect Harrassment and High Snow

Activities by Proportions

Seasons		a[1]	b	c	d	e	f	g
	1[2]	0.48	0.40	0.05	0.08	0.00	0.74	0.23
	2	0.45	0.47	0.05	0.03	0.00	0.60	0.36
	3	0.49	0.45	0.02	0.04	0.00	0.94	0.06
	4	0.44	0.33	0.02	0.21	0.00	0.96	0.00
S	5	0.25	0.15	0.28	0.20	0.07	0.84	0.00
e	6	0.25	0.20	0.28	0.20	0.07	0.84	0.00
a	7	0.25	0.20	0.28	0.20	0.07	0.84	0.00
s	8	0.23	0.13	0.27	0.30	0.07	0.84	0.00
o	9	0.28	0.17	0.32	0.15	0.08	0.84	0.00
n	10	0.23	0.13	0.27	0.25	0.12	0.84	0.00
s	11	0.52	0.17	0.15	0.12	0.04	0.84	0.00
	12	0.46	0.24	0.06	0.23	0.02	0.84	0.00
	13	0.41	0.28	0.08	0.21	0.02	0.84	0.00
	14	0.46	0.24	0.06	0.23	0.01	0.84	0.00
	15	0.53	0.26	0.05	0.16	0.00	0.73	0.23

[1] Activities: a=proportion of time spent foraging,
b=proportion of time spent lying,
c=proportion of time spent standing,
d=proportion of time spent walking
e=proportion of time spent running,
f=eating intensity (proportion of foraging period actually spent eating,
g=pawing intensity (proportion of foraging period spent cratering.

[2] See Table 1 of THE ENERGY MODEL for season definitions

Table B. Seasonal values of neutral detergent fiber for plant groups

Seasons	Plant Group a[1]	b	c	d	e	f	g	h	i	j
1[2]	.76	.40	.35	.40	.65	.30	.36	.50	.75	0
2	.76	.40	.35	.40	.65	.30	.36	.50	.75	0
3	.76	.40	.35	.40	.65	.30	.36	.50	.75	0
4	.76	.40	.35	.40	.65	.30	.36	.50	.75	0
5	.76	.40	.35	.40	.58	.13	.29	.22	.75	.57
6	.76	.40	.35	.40	.60	.13	.30	.22	.75	.57
7	.76	.40	.35	.40	.64	.15	.30	.23	.75	.57
8	.76	.40	.35	.40	.65	.18	.31	.24	.75	0
9	.76	.40	.35	.40	.65	.19	.32	.24	.75	0
10	.76	.40	.35	.40	.65	.20	.33	.24	.75	0
11	.76	.40	.35	.40	.65	.30	.36	.50	.75	0
12	.76	.40	.35	.40	.65	.30	.36	.50	.75	0
13	.76	.40	.35	.40	.65	.30	.36	.50	.75	0
14	.76	.40	.35	.40	.65	.30	.36	.50	.75	0
15	.76	.40	.35	.40	.65	.30	.36	.50	.75	0

[1] Plant Groups: a=moss,
b=lichens,
c=mushrooms,
d=horsetails,
e=graminoids,
f=deciduous shrubs,
g=evergreen shrubs,
h=forbs,
i=standing dead material,
j=eriophorum heads.

[2] See Table 1 of THE ENERGY MODEL for season definitions

Table C. Example seasonal plant dry matter digestibilities (g/m^2)

Plant Groups

Seasons	a[1]	b	c	d	e	f	g	h	i	j
1[2]	.10	.55	.85	.55	.25	.30	.50	.50	.30	.00
2	.12	.55	.85	.55	.25	.30	.50	.50	.30	.00
3	.15	.60	.85	.55	.25	.30	.50	.50	.30	.00
4	.17	.70	.85	.55	.25	.30	.50	.50	.30	.00
5	.20	.70	.85	.55	.77	.50	.50	.80	.30	.85
6	.20	.70	.85	.55	.76	.72	.50	.80	.25	.85
7	.20	.70	.85	.55	.74	.72	.55	.80	.25	.85
8	.20	.70	.85	.55	.70	.70	.55	.78	.25	.00
9	.15	.70	.85	.55	.61	.69	.50	.78	.25	.00
10	.15	.70	.85	.55	.50	.69	.50	.60	.25	.00
11	.15	.60	.85	.55	.40	.63	.50	.60	.25	.00
12	.15	.55	.85	.55	.30	.60	.50	.58	.30	.00
13	.15	.55	.85	.55	.30	.60	.50	.50	.30	.00
14	.15	.55	.85	.55	.25	.40	.50	.50	.30	.00
15	.10	.55	.85	.55	.25	.30	.50	.50	.30	.00

[1] Plant Groups: a=moss,
b=lichens,
c=mushrooms,
d=horsetails,
e=graminoids,
f=deciduous shrubs,
g=evergreen shrubs,
h=forbs,
i=standing dead material,
j=eriophorum heads.

[2] See Table 1 of THE ENERGY MODEL for season definitions

Table D1. Example forage and diet characteristics for the Basic Scenario in usual snow years

A	B	C	D	E
a	1	.09	300	0.8
	2	.07	300	0.8
	3	.08	300	0.8
	4	.10	300	0.8
	5	.39	300	0.8
	6	.47	300	0.8
	7	.06	300	0.8
	8	.00	300	0.8
	9	.00	300	0.8
	10	0.00	300	0.8
	11	0.07	300	0.8
	12	0.03	300	0.8
	13	0.10	300	0.8
	14	0.05	300	0.8
	15	0.07	300	0.8
b	1	.74	280	0.5
	2	.79	280	0.5
	3	.70	435	0.5
	4	.61	70	1.0
	5	.25	25	0.5
	6	.17	25	0.5
	7	.14	25	0.5
	8	.14	25	0.5
	9	.13	25	0.5
	10	0.14	25	0.5
	11	0.61	25	0.5
	12	0.82	175	0.5
	13	0.66	435	0.5
	14	0.76	280	0.5
	15	0.74	280	0.5
c	1	.00	0	5.6
	2	.00	0	5.6
	3	.00	0	5.6
	4	.00	0	5.6
	5	.00	0	0.0
	6	.00	0	0.0
	7	.00	0	0.0
	8	.00	0	0.0
	9	.00	0	0.0
	10	0.10	0	5.6
	11	0.10	0	5.6
	12	0.07	0	5.6
	13	0.00	0	5.6
	14	0.00	0	5.6
	15	0.00	0	5.6
d	1	.04	5	1.2
	2	.03	5	1.2
	3	.06	5	1.2

[1]A is the plant group letter
- a=moss
- b=lichens
- c=mushrooms
- d=horsetails
- e=graminoids
- f=deciduous shrubs
- g=evergreen shrubs
- h=forbs
- i=standing dead material
- j=eriophorum heads

[2]B is the season number (see Table 1 for season definitions).

[3]C is the proportion in the diet

[4]D is available biomass (g dry matter/m^2 live green).

[5]E is nitrogen (g/100g dry matter).

	4	.03,5,1.2
	5	.03,1,1.2
	6	.00,1,1.2
	7	.02,1,1.2
	8	.02,22,3.2
	9	.01,22,2.2
	10	0.00,22,2.1
	11	0.01,5,1.2
	12	0.02,5,1.2
	13	0.07,5,1.2
	14	0.12,5,1.2
	15	0.09,5,1.2
e	1	.03,5,0.8
	2	.02,5,0.8
	3	.05,5,0.8
	4	.04,5,0.8
	5	.00,7,1.0
	6	.00,11,1.8
	7	.00,31,2.4
	8	.03,50,2.0
	9	.01,54,1.9
	10	0.03,56,1.4
	11	0.02,31,0.8
	12	0.01,10,0.8
	13	0.09,5,0.8
	14	0.02,5,0.8
	15	0.03,5,0.8
f	1	.03,5,0.8
	2	.02,5,0.8
	3	.03,5,0.8
	4	.12,9,0.8
	5	.03,9,2.4
	6	.01,9,4.5
	7	.32,9,4.9
	8	.41,31,3.9
	9	.43,40,2.8
	10	0.41,77,2.6
	11	0.19,40,0.8
	12	0.01,10,0.8
	13	0.03,5,0.8
	14	0.01,5,0.8
	15	0.02,5,0.8
g	1	0.06,76,0.9
	2	0.06,76,0.9
	3	0.07,76,0.9
	4	0.09,76,0.9
	5	0.08,76,0.9
	6	0.08,76,0.9
	7	0.05,76,0.9
	8	0.02,76,0.9
	9	0.02,76,0.9
	10	0.00,76,0.9
	11	0.00,76,0.9
	12	0.04,76,0.9

	13	0.05,76,0.9
	14	0.04,76,0.9
	15	0.05,76,0.9
h	1	.01,0,1.6
	2	.01,0,1.6
	3	.01,0,1.6
	4	.01,0,1.6
	5	.01,1,3.1
	6	.02,4,3.5
	7	.29,7,5.4
	8	.33,21,4.1
	9	.35,25,3.8
	10	0.27,22,3.6
	11	0.00,8,1.6
	12	0.00,3,1.6
	13	0.00,0,1.6
	14	0.00,0,1.6
	15	0.00,0,1.6
i	1	.00,250,0.5
	2	.00,250,0.5
	3	.00,250,0.5
	4	.00,150,0.5
	5	.06,250,0.5
	6	.06,250,0.5
	7	.05,250,0.5
	8	.05,250,0.5
	9	.05,250,0.5
	10	0.05,250,0.5
	11	0.00,250,0.5
	12	0.00,250,0.5
	13	0.00,250,0.5
	14	0.00,250,0.5
	15	0.00,250,0.5
j	1	.00,0,0.0
	2	.00,0,0.0
	3	.00,0,0.0
	4	.00,0,0.0
	5	.15,1,3.1
	6	.19,2,2.5
	7	.07,5,2.4
	8	.00,0,0.0
	9	.00,0,0.0
	10	0.00,0,0.0
	11	0.00,0,0.0
	12	0.00,0,0.0
	13	0.00,0,0.0
	14	0.00,0,0.0
	15	0.00,0,0.0

Table D2. Example forage and diet characteristics for the Basic Scenario for years when caribou move to areas of deep snow

A	B	C	D	E
a	1	0.09,	300,	0.8
	2	0.07,	300,	0.8
	3	0.08,	300,	0.8
	4	0.10,	300,	0.8
	5	0.39,	300,	0.8
	6	0.47,	300,	0.8
	7	0.06,	300,	0.8
	8	0.00,	300,	0.8
	9	0.00,	300,	0.8
	10	0.00,	300,	0.8
	11	0.07,	300,	0.8
	12	0.03,	300,	0.8
	13	0.10,	300,	0.8
	14	0.05,	300,	0.8
	15	0.07,	300,	0.8
b	1	0.74,	540,	0.63
	2	0.79,	540,	0.63
	3	0.70,	435,	0.63
	4	0.61,	70,	1.0
	5	0.25,	25,	0.5
	6	0.17,	25,	0.5
	7	0.14,	25,	0.5
	8	0.14,	25,	0.5
	9	0.13,	25,	0.5
	10	0.14,	25,	0.5
	11	0.61,	25,	0.63
	12	0.82,	175,	0.63
	13	0.66,	435,	0.63
	14	0.76,	540,	0.63
	15	0.74,	540,	0.63
c	1	0.00,	0,	5.6
	2	0.00,	0,	5.6
	3	0.00,	0,	5.6
	4	0.00,	0,	5.6
	5	0.00,	0,	0.0
	6	0.00,	0,	0.0
	7	0.00,	0,	0.0
	8	0.00,	0,	0.0
	9	0.00,	0,	0.0
	10	0.10,	0,	5.6
	11	0.10,	0,	5.6
	12	0.07,	0,	5.6
	13	0.00,	0,	5.6
	14	0.00,	0,	5.6
	15	0.00,	0,	5.6
d	1	0.04,	5,	1.2
	2	0.03,	5,	1.2
	3	0.06,	5,	1.2

[1] A is the plant group letter
- a=moss
- b=lichens
- c=mushrooms
- d=horsetails
- e=graminoids
- f=deciduous shrubs
- g=evergreen shrubs
- h=forbs
- i=standing dead material
- j=eriophorum heads

[2] B is the season number (see Table 1 for season definitions).

[3] C is the proportion in the diet

[4] D is available biomass (g dry matter/m^2 live green).

[5] E is nitrogen (g/100g dry matter).

	4	0.03,5,1.2
	5	0.03,1,1.2
	6	0.00,1,1.2
	7	0.02,1,1.2
	8	0.02,22,3.2
	9	0.01,22,2.2
	10	0.00,22,2.1
	11	0.01,5,1.2
	12	0.02,5,1.2
	13	0.07,5,1.2
	14	0.12,5,1.2
	15	0.09,5,1.2
e	1	0.03,5,0.8
	2	0.02,5,0.8
	3	0.05,5,0.8
	4	0.04,5,0.8
	5	0.00,7,1.0
	6	0.00,11,1.8
	7	0.00,31,2.4
	8	0.03,50,2.0
	9	0.01,54,1.9
	10	0.03,56,1.4
	11	0.02,31,0.8
	12	0.01,10,0.8
	13	0.09,5,0.8
	14	0.02,5,0.8
	15	0.03,5,0.8
f	1	0.03,5,0.8
	2	0.02,5,0.8
	3	0.03,5,0.8
	4	0.12,9,0.8
	5	0.03,9,2.4
	6	0.01,9,4.5
	7	0.32,9,4.9
	8	0.41,31,3.9
	9	0.43,40,2.8
	10	0.41,77,2.6
	11	0.19,40,0.8
	12	0.01,10,0.8
	13	0.03,5,0.8
	14	0.01,5,0.8
	15	0.02,5,0.8
g	1	0.06,76,0.9
	2	0.06,76,0.9
	3	0.07,76,0.9
	4	0.09,76,0.9
	5	0.08,76,0.9
	6	0.08,76,0.9
	7	0.05,76,0.9
	8	0.02,76,0.9
	9	0.02,76,0.9
	10	0.00,76,0.9
	11	0.00,76,0.9
	12	0.04,76,0.9

	13	0.05,76,0.9
	14	0.04,76,0.9
	15	0.05,76,0.9
h	1	0.01,0,1.6
	2	0.01,0,1.6
	3	0.01,0,1.6
	4	0.01,0,1.6
	5	0.01,1,3.1
	6	0.02,4,3.5
	7	0.29,7,5.4
	8	0.33,21,4.1
	9	0.35,25,3.8
	10	0.27,22,3.6
	11	0.00,8,1.6
	12	0.00,3,1.6
	13	0.00,0,1.6
	14	0.00,0,1.6
	15	0.00,0,1.6
i	1	0.0,250,0.5
	2	0.0,250,0.5
	3	0.0,250,0.5
	4	0.0,150,0.5
	5	0.06,250,0.5
	6	0.06,250,0.5
	7	0.05,250,0.5
	8	0.05,250,0.5
	9	0.05,250,0.5
	10	0.05,250,0.5
	11	0.0,250,0.5
	12	0.0,250,0.5
	13	0.0,250,0.5
	14	0.0,250,0.5
	15	0.0,250,0.5
j	1	0.00,0,0.0
	2	0.00,0,0.0
	3	0.00,0,0.0
	4	0.00,0,0.0
	5	0.15,1,3.1
	6	0.19,2,2.5
	7	0.07,5,2.4
	8	0.00,0,0.0
	9	0.00,0,0.0
	10	0.00,0,0.0
	11	0.00,0,0.0
	12	0.00,0,0.0
	13	0.00,0,0.0
	14	0.00,0,0.0
	15	0.00,0,0.0

Table D3. Example forage and diet characteristics for the Lowland Scenario in usual snow years

A	B	C D E
a	1	0.09,300,0.8
	2	0.07,380,0.8
	3	0.08,300,0.8
	4	0.10,300,0.8
	5	0.24,38,0.8
	6	0.26,38,0.8
	7	0.04,38,0.8
	8	0.00,38,0.8
	9	0.00,38,0.8
	10	0.00,38,0.8
	11	0.07,300,0.8
	12	0.03,300,0.8
	13	0.10,300,0.8
	14	0.05,300,0.8
	15	0.07,300,0.8
b	1	0.74,280,0.5
	2	0.79,280,0.5
	3	0.70,435,0.5
	4	0.61,70,1.0
	5	0.44,2,0.5
	6	0.37,2,0.5
	7	0.22,2,0.5
	8	0.08,2,0.5
	9	0.02,2,0.5
	10	0.02,2,0.5
	11	0.61,25,0.5
	12	0.82,175,0.5
	13	0.66,435,0.5
	14	0.76,280,0.5
	15	0.74,280,0.5
c	1	0.00,0,5.6
	2	0.00,0,5.6
	3	0.00,0,5.6
	4	0.00,0,5.6
	5	0.00,0,0.0
	6	0.00,0,0.0
	7	0.00,0,0.0
	8	0.00,0,0.0
	9	0.00,0,0.0
	10	0.10,0,0.0
	11	0.10,0,5.6
	12	0.07,0,5.6
	13	0.00,0,5.6
	14	0.00,0,5.6
	15	0.00,0,5.6
d	1	0.04,5,1.2
	2	0.03,5,1.2
	3	0.06,5,1.2

[1] A is the plant group letter
- a=moss
- b=lichens
- c=mushrooms
- d=horsetails
- e=graminoids
- f=deciduous shrubs
- g=evergreen shrubs
- h=forbs
- i=standing dead material
- j=eriophorum heads

[2] B is the season number (see Table 1 for season definitions).

[3] C is the proportion in the diet

[4] D is available biomass (g dry matter/m^2 live green).

[5] E is nitrogen (g/100g dry matter).

	3	0.06,5,1.2
	4	0.03,5,1.2
	5	0.00,0,0.0
	6	0.00,0,0.0
	7	0.00,0,0.0
	8	0.00,0,0.0
	9	0.00,0,0.0
	10	0.00,0,0.0
	11	0.01,5,1.2
	12	0.02,5,1.2
	13	0.07,5,1.2
	14	0.12,5,1.2
	15	0.09,5,1.2
e	1	0.03,5,0.8
	2	0.02,5,0.8
	3	0.05,5,0.8
	4	0.04,5,0.8
	5	0.11,9,0.8
	6	0.14,11,1.8
	7	0.37,29,2.4
	8	0.44,35,2.3
	9	0.48,38,2.1
	10	0.53,42,1.4
	11	0.02,31,0.8
	12	0.01,10,0.8
	13	0.09,5,0.8
	14	0.02,5,0.8
	15	0.03,5,0.8
f	1	0.03,5,0.8
	2	0.02,5,0.8
	3	0.03,5,0.8
	4	0.12,9,0.8
	5	0.00,0,0.0
	6	0.00,0,0.0
	7	0.05,1,4.8
	8	0.16,2,3.9
	9	0.16,3,2.5
	10	0.08,6,2.2
	11	0.19,40,0.8
	12	0.01,10,0.8
	13	0.03,5,0.8
	14	0.01,5,0.8
	15	0.02,5,0.8
g	1	0.06,76,0.9
	2	0.06,76,0.9
	3	0.07,76,0.9
	4	0.09,76,0.9
	5	0.08,1,0.9
	6	0.08,1,0.9
	7	0.05,1,0.9
	8	0.02,1,0.9
	9	0.02,1,0.9
	10	0.00,1,0.9
	11	0.00,76,0.9

	12	0.04,76,0.9
	13	0.05,76,0.9
	14	0.04,76,0.9
	15	0.05,76,0.9
h	1	0.01,0,1.6
	2	0.01,0,1.6
	3	0.01,0,1.6
	4	0.01,0,1.6
	5	0.00,0,0.0
	6	0.00,0,0.0
	7	0.00,0,0.0
	8	0.00,2,1.8
	9	0.00,5,1.5
	10	0.00,2,1.6
	11	0.00,8,1.6
	12	0.00,3,1.6
	13	0.00,0,1.6
	14	0.00,0,1.6
	15	0.00,0,1.6
i	1	0.00,250,0.5
	2	0.00,250,0.5
	3	0.00,250,0.5
	4	0.00,250,0.5
	5	0.13,40,0.5
	6	0.15,40,0.5
	7	0.27,40,0.5
	8	0.30,40,0.5
	9	0.32,40,0.5
	10	0.35,40,0.5
	11	0.00,250,0.5
	12	0.00,250,0.5
	13	0.00,250,0.5
	14	0.00,250,0.5
	15	0.00,250,0.5
j	1	0.00,0,0
	2	0.00,0,0
	3	0.00,0,0
	4	0.00,0,0
	5	0.00,10,0
	6	0.00,10,0
	7	0.00,10,0
	8	0.00,0,0
	9	0.00,0,0
	10	0.00,0,0
	11	0.00,0,0
	12	0.00,0,0
	13	0.00,0,0
	14	0.00,0,0
	15	0.00,0,0

Table D4. Example forage and diet characteristics for the Lowland Scenario for years when caribou move to areas of deep snow

A	B	C	D	E
a	1	0.09	300	0.8
	2	0.07	300	0.8
	3	0.08	300	0.8
	4	0.10	300	0.8
	5	0.24	38	0.8
	6	0.26	38	0.8
	7	0.04	38	0.8
	8	0.00	38	0.8
	9	0.00	38	0.8
	10	0.00	38	0.8
	11	0.07	300	0.8
	12	0.03	300	0.8
	13	0.10	300	0.8
	14	0.05	300	0.8
	15	0.07	300	0.8
b	1	0.74	540	0.5
	2	0.79	540	0.5
	3	0.70	435	0.5
	4	0.61	70	1.0
	5	0.44	2	0.5
	6	0.37	2	0.5
	7	0.22	2	0.5
	8	0.08	2	0.5
	9	0.02	2	0.5
	10	0.02	2	0.5
	11	0.61	25	0.5
	12	0.82	175	0.5
	13	0.66	435	0.5
	14	0.76	540	0.5
	15	0.74	540	0.5
c	1	0.00	0	5.6
	2	0.00	0	5.6
	3	0.00	0	5.6
	4	0.00	0	5.6
	5	0.00	0	0.0
	6	0.00	0	0.0
	7	0.00	0	0.0
	8	0.00	0	0.0
	9	0.00	0	0.0
	10	0.10	0	0.0
	11	0.10	0	5.6
	12	0.07	0	5.6
	13	0.00	0	5.6
	14	0.00	0	5.6
	15	0.00	0	5.6
d	1	0.04	5	1.2
	2	0.03	5	1.2
	3	0.06	5	1.2

[1]A is the plant group letter
- a=moss
- b=lichens
- c=mushrooms
- d=horsetails
- e=graminoids
- f=deciduous shrubs
- g=evergreen shrubs
- h=forbs
- i=standing dead material
- j=eriophorum heads

[2]B is the season number (see Table 1 for season definitions).

[3]C is the proportion in the diet

[4]D is available biomass (g dry matter/m^2 live green).

[5]E is nitrogen (g/100g dry matter).

	3	0.06,5,1.2
	4	0.03,5,1.2
	5	0.00,0,0.0
	6	0.00,0,0.0
	7	0.00,0,0.0
	8	0.00,0,0.0
	9	0.00,0,0.0
	10	0.00,0,0.0
	11	0.01,5,1.2
	12	0.02,5,1.2
	13	0.07,5,1.2
	14	0.12,5,1.2
	15	0.09,5,1.2
e	1	0.03,5,0.8
	2	0.02,5,0.8
	3	0.05,5,0.8
	4	0.04,5,0.8
	5	0.11,9,0.8
	6	0.14,11,1.8
	7	0.37,29,2.4
	8	0.44,35,2.3
	9	0.48,38,2.1
	10	0.53,42,1.4
	11	0.02,31,0.8
	12	0.01,10,0.8
	13	0.09,5,0.8
	14	0.02,5,0.8
	15	0.03,5,0.8
f	1	0.03,5,0.8
	2	0.02,5,0.8
	3	0.03,5,0.8
	4	0.12,9,0.8
	5	0.00,0,0.0
	6	0.00,0,0.0
	7	0.05,1,4.8
	8	0.16,2,3.9
	9	0.16,3,2.5
	10	0.08,6,2.2
	11	0.19,40,0.8
	12	0.01,10,0.8
	13	0.03,5,0.8
	14	0.01,5,0.8
	15	0.02,5,0.8
g	1	0.06,76,0.9
	2	0.06,76,0.9
	3	0.07,76,0.9
	4	0.09,76,0.9
	5	0.08,1,0.9
	6	0.08,1,0.9
	7	0.05,1,0.9
	8	0.02,1,0.9
	9	0.02,1,0.9
	10	0.02,1,0.9
	11	0.00,76,0.9

	12	0.04,76,0.9
	13	0.05,76,0.9
	14	0.04,76,0.9
	15	0.05,76,0.9
h	1	0.01,0,1.6
	2	0.01,0,1.6
	3	0.01,0,1.6
	4	0.01,0,1.6
	5	0.00,0,0.0
	6	0.00,0,0.0
	7	0.00,0,0.0
	8	0.00,2,1.8
	9	0.00,5,1.5
	10	0.00,2,1.6
	11	0.00,8,1.6
	12	0.00,3,1.6
	13	0.00,0,1.6
	14	0.00,0,1.6
	15	0.00,0,1.6
i	1	0.00,250,0.5
	2	0.00,250,0.5
	3	0.00,250,0.5
	4	0.00,250,0.5
	5	0.13,40,0.5
	6	0.15,40,0.5
	7	0.27,40,0.5
	8	0.30,40,0.5
	9	0.32,40,0.5
	10	0.35,40,0.5
	11	0.00,250,0.5
	12	0.00,250,0.5
	13	0.00,250,0.5
	14	0.00,250,0.5
	15	0.00,250,0.5
j	1	0.00,0,0
	2	0.00,0,0
	3	0.00,0,0
	4	0.00,0,0
	5	0.00,1,0
	6	0.00,10,0
	7	0.00,10,0
	8	0.00,0,0
	9	0.00,0,0
	10	0.00,0,0
	11	0.00,0,0
	12	0.00,0,0
	13	0.00,0,0
	14	0.00,0,0
	15	0.00,0,0

Table D5. Example forage and diet characteristics for the Upland Scenario in usual snow years

A	B	C D E
a	1	0.09,300,0.8
	2	0.07,300,0.8
	3	0.08,300,0.8
	4	0.10,300,0.8
	5	0.09,64,0.8
	6	0.05,64,0.8
	7	0.01,64,0.8
	8	0.00,64,0.8
	9	0.00,64,0.8
	10	0.00,64,0.8
	11	0.07,300,0.8
	12	0.03,300,0.8
	13	0.10,300,0.8
	14	0.05,300,0.8
	15	0.07,300,0.8
b	1	0.74,280,0.5
	2	0.79,280,0.5
	3	0.70,435,0.5
	4	0.61,70,1.0
	5	0.55,13,0.5
	6	0.37,13,0.5
	7	0.14,13,0.5
	8	0.14,13,0.5
	9	0.13,13,0.5
	10	0.14,13,0.5
	11	0.61,25,0.5
	12	0.82,175,0.5
	13	0.66,435,0.5
	14	0.76,280,0.5
	15	0.74,280,0.5
c	1	0.00,0,5.6
	2	0.00,0,5.6
	3	0.00,0,5.6
	4	0.00,0,5.6
	5	0.00,0,0.0
	6	0.00,0,0.0
	7	0.00,0,0.0
	8	0.00,0,0.0
	9	0.00,0,0.0
	10	0.10,0,0.0
	11	0.10,0,5.6
	12	0.07,0,5.6
	13	0.00,0,5.6
	14	0.00,0,5.6
	15	0.00,0,5.6
d	1	0.04,5,1.2
	2	0.03,5,1.2
	3	0.06,5,1.2

[1]A is the plant group letter
- a=moss
- b=lichens
- c=mushrooms
- d=horsetails
- e=graminoids
- f=deciduous shrubs
- g=evergreen shrubs
- h=forbs
- i=standing dead material
- j=eriophorum heads

[2]B is the season number (see Table 1 for season definitions).

[3]C is the proportion in the diet

[4]D is available biomass (g dry matter/m^2 live green).

[5]E is nitrogen (g/100g dry matter).

```
   4 0.03,5,1.2
   5 0.00,0,0.0
   6 0.01,0,0.0
   7 0.01,0,0.0
   8 0.02,0,0.0
   9 0.01,0,0.0
  10 0.00,0,0.0
  11 0.01,5,1.2
  12 0.02,5,1.2
  13 0.07,5,1.2
  14 0.12,5,1.2
  15 0.09,5,1.2
e  1 0.03,5,0.8
   2 0.02,5,0.8
   3 0.05,5,0.8
   4 0.04,5,0.8
   5 0.00,7,3.1
   6 0.00,11,2.5
   7 0.00,31,2.1
   8 0.03,50,2.2
   9 0.01,54,1.9
  10 0.03,56,1.4
  11 0.02,31,0.8
  12 0.01,10,0.8
  13 0.09,5,0.8
  14 0.02,5,0.8
  15 0.03,5,0.8
f  1 0.03,5,0.8
   2 0.02,5,0.8
   3 0.03,5,0.8
   4 0.12,9,0.8
   5 0.00,0,0.0
   6 0.01,0,0.0
   7 0.07,6,4.8
   8 0.41,31,3.9
   9 0.43,40,2.5
  10 0.41,77,2.2
  11 0.19,40,0.8
  12 0.01,10,0.8
  13 0.03,5,0.8
  14 0.01,5,0.8
  15 0.02,5,0.8
g  1 0.06,76,0.9
   2 0.06,76,0.9
   3 0.07,76,0.9
   4 0.09,76,0.9
   5 0.17,76,0.9
   6 0.04,76,0.9
   7 0.02,76,0.9
   8 0.02,76,0.9
   9 0.02,76,0.9
  10 0.00,76,0.9
  11 0.00,76,0.9
  12 0.04,76,0.9
```

```
   13 0.05,76,0.9
   14 0.04,76,0.9
   15 0.05,76,0.9
h   1 0.01,0,1.6
    2 0.01,0,1.6
    3 0.01,0,1.6
    4 0.01,0,1.6
    5 0.04,0,0.0
    6 0.00,0,0.0
    7 0.00,0,0.0
    8 0.33,2,1.8
    9 0.35,5,1.5
   10 0.27,2,1.6
   11 0.00,8,1.6
   12 0.00,3,1.6
   13 0.00,0,1.6
   14 0.00,0,1.6
   15 0.00,0,1.6
i   1 0.00,250,0.5
    2 0.00,250,0.5
    3 0.00,250,0.5
    4 0.00,250,0.5
    5 0.06,40,0.5
    6 0.07,40,0.5
    7 0.09,40,0.5
    8 0.05,40,0.5
    9 0.05,40,0.5
   10 0.05,40,0.5
   11 0.00,250,0.5
   12 0.00,250,0.5
   13 0.00,250,0.5
   14 0.00,250,0.5
   15 0.00,250,0.5
j   1 0.00,0,0.0
    2 0.00,0,0.0
    3 0.00,0,0.0
    4 0.00,0,0.0
    5 0.09,1,3.1
    6 0.45,2,2.5
    7 0.66,5,2.4
    8 0.00,0,0.0
    9 0.00,0,0.0
   10 0.00,0,0.0
   11 0.00,0,0.0
   12 0.00,0,0.0
   13 0.00,0,0.0
   14 0.00,0,0.0
   15 0.00,0,0.0
```

Table D6. Example forage and diet characteristics for the Upland Scenario for years when caribou move to areas of deep snow

A	B	C	D	E
a	1	0.09,	300,	0.8
	2	0.07,	300,	0.8
	3	0.08,	300,	0.8
	4	0.10,	300,	0.8
	5	0.09,	64,	0.8
	6	0.05,	64,	0.8
	7	0.01,	64,	0.8
	8	0.00,	64,	0.8
	9	0.00,	64,	0.8
	10	0.00,	64,	0.8
	11	0.07,	300,	0.8
	12	0.03,	300,	0.8
	13	0.10,	300,	0.8
	14	0.05,	300,	0.8
	15	0.07,	300,	0.8
b	1	0.74,	540,	0.5
	2	0.79,	540,	0.5
	3	0.70,	435,	0.5
	4	0.61,	70,	1.0
	5	0.55,	25,	0.5
	6	0.37,	13,	0.5
	7	0.14,	13,	0.5
	8	0.14,	13,	0.5
	9	0.13,	13,	0.5
	10	0.14,	13,	0.5
	11	0.61,	25,	0.5
	12	0.82,	175,	0.5
	13	0.66,	435,	0.5
	14	0.76,	540,	0.5
	15	0.74,	540,	0.5
c	1	0.00,	0,	5.6
	2	0.00,	0,	5.6
	3	0.00,	0,	5.6
	4	0.00,	0,	5.6
	5	0.00,	0,	0.0
	6	0.00,	0,	0.0
	7	0.00,	0,	0.0
	8	0.00,	0,	0.0
	9	0.00,	0,	0.0
	10	0.10,	0,	5.6
	11	0.10,	0,	5.6
	12	0.07,	0,	5.6
	13	0.00,	0,	5.6
	14	0.00,	0,	5.6
	15	0.00,	0,	5.6
d	1	0.04,	5,	1.2
	2	0.03,	5,	1.2
	3	0.06,	5,	1.2

[1]A is the plant group letter
- a=moss
- b=lichens
- c=mushrooms
- d=horsetails
- e=graminoids
- f=deciduous shrubs
- g=evergreen shrubs
- h=forbs
- i=standing dead material
- j=eriophorum heads

[2]B is the season number (see Table 1 for season definitions).

[3]C is the proportion in the diet

[4]D is available biomass (g dry matter/m^2 live green).

[5]E is nitrogen (g/100g dry matter).

	4	0.03,5,1.2
	5	0.00,0,0.0
	6	0.01,0,0.0
	7	0.01,0,0.0
	8	0.02,0,0.0
	9	0.01,0,0.0
	10	0.00,0,0.0
	11	0.01,5,1.2
	12	0.02,5,1.2
	13	0.07,5,1.2
	14	0.12,5,1.2
	15	0.09,5,1.2
e	1	0.03,5,0.8
	2	0.02,5,0.8
	3	0.05,5,0.8
	4	0.04,5,0.8
	5	0.00,7,3.1
	6	0.00,11,2.5
	7	0.00,31,2.1
	8	0.03,50,2.2
	9	0.01,54,1.9
	10	0.03,56,1.4
	11	0.02,31,0.8
	12	0.01,10,0.8
	13	0.09,5,0.8
	14	0.02,5,0.8
	15	0.03,5,0.8
f	1	0.03,5,0.8
	2	0.02,5,0.8
	3	0.03,5,0.8
	4	0.12,9,0.8
	5	0.00,0,0.0
	6	0.01,0,0.0
	7	0.07,6,4.8
	8	0.41,31,3.9
	9	0.43,40,2.5
	10	0.41,77,2.2
	11	0.19,40,0.8
	12	0.01,10,0.8
	13	0.03,5,0.8
	14	0.01,5,0.8
	15	0.02,5,0.8
g	1	0.06,76,0.9
	2	0.06,76,0.9
	3	0.07,76,0.9
	4	0.09,76,0.9
	5	0.17,76,0.9
	6	0.04,76,0.9
	7	0.02,76,0.9
	8	0.02,76,0.9
	9	0.02,76,0.9
	10	0.00,76,0.9
	11	0.00,76,0.9
	12	0.04,76,0.9

	13	0.05,76,0.9
	14	0.04,76,0.9
	15	0.05,76,0.9
h	1	0.01,0,1.6
	2	0.01,0,1.6
	3	0.01,0,1.6
	4	0.01,0,1.6
	5	0.04,0,0.0
	6	0.00,0,0.0
	7	0.00,0,0.0
	8	0.33,3,1.8
	9	0.35,8,1.5
	10	0.27,9,1.6
	11	0.00,8,1.6
	12	0.00,3,1.6
	13	0.00,0,1.6
	14	0.00,0,1.6
	15	0.00,0,1.6
i	1	0.00,250,0.5
	2	0.00,250,0.5
	3	0.00,250,0.5
	4	0.00,250,0.5
	5	0.06,250,0.5
	6	0.07,250,0.5
	7	0.09,250,0.5
	8	0.05,250,0.5
	9	0.05,250,0.5
	10	0.05,250,0.5
	11	0.00,250,0.5
	12	0.00,250,0.5
	13	0.00,250,0.5
	14	0.00,250,0.5
	15	0.00,250,0.5
j	1	0.00,0,0.0
	2	0.00,0,0.0
	3	0.00,0,0.0
	4	0.00,0,0.0
	5	0.09,1,3.1
	6	0.45,2,2.5
	7	0.66,5,2.4
	8	0.00,0,0.0
	9	0.00,0,0.0
	10	0.00,0,0.0
	11	0.00,0,0.0
	12	0.00,0,0.0
	13	0.00,0,0.0
	14	0.00,0,0.0
	15	0.00,0,0.0

Appendix 2

Variable List for Energy Model

Variable	Description
ACTBUG(7,15)	Activity budget data for 7 activities and 15 seasons
ACTCST	Cost of activities, growth, and fattening ($kJ \cdot kg^{-0.75}$)
ACTDIM	Array size for activity budget data
AR(10)	The attack rates of caribou on each of the 10 plant groups ($ha \cdot min^{-1}$)
CCI	Cell content intake ($g \cdot h^{-1}$)
CCNRG	Energy available from cell contents in the rumen ($kJ \cdot h^{-1}$)
CCON	Identifies attributes of cell contents
CELCON	Amount of the cell content pool in the rumen (g)
CELWAL	Amount of the cell wall pool in the rumen (g)
CONSEL	Constraint selected to act on food intake
CONSTR(3)	Constraints operating on food intake CONST(1)=metabolic, Const(2)=logistic, CONST(3)=rumen capacity
CWALL	Identifies attributes of cell wall
CWI	Cell wall intake ($g \cdot h^{-1}$)
CWNRG	Energy available from cell wall contents in the rumen ($kJ \cdot h^{-1}$)
D,PLAMDA,	Parameters used to fit curves describing the rate at which caribou encounter forage
DAY	Number of days since the beginning of the simulation
DFI	Digestible forage intake ($g \cdot h^{-1}$)
DPBIO(10)	Daily available biomass of each plant group ($g \cdot m^{-2}$, live green)

DPCWAL(10)	Daily values for proportion of cell wall content for each plant group
DPDIG(10)	Daily digestibilities of each forage group (proportion)
DPDP(10)	Daily dietary proportions for each plant group
DPNIT(10)	Daily values of nitrogen for each plant group (%)
DPNRG(2)	Daily values of digestible energy for cell content and cell wall material (kJ/g)
EATINT	Proportion of foraging time actually spent eating
FB	Available forage biomass converted to dry matter (kg/ha)
FECES	Amount (g) of fecal output each day
FEED	Proportion of time spent feeding
FIP	Potential forage intake for each plant group ($g \cdot h^{-1}$)
FOODIN	Actual food intake determined by applying the minimum constraint ($g \cdot h^{-1}$)
GT	Eating time linearly interpolated to give daily values (proportion)
HACOST	Energetic cost of activities ($kJ \cdot kg^{-1}$)
K(2)	Digestion rates of cell content (1) and cell wall (2) material (proportion/h)
KJPG	The energy contained in each gram of forage ingested ($kJ \cdot g^{-1}$)
KNDIG(10)	Passage rate of non-digestible material for each of the 10 plant groups (proportion/h)
LIE	Proportion of time spent lying
MAXDIM1	Maximum number of plotting variables used in simulation.
MAXDIM2	Maximum number of iterations.
MEC(2)	The factors converting digestible energy of cell content (1) and cell wall (2) to metabolizable energy of cell content and cell wall, respectively.

MEI	Metabolizable energy intake for each hour and summed for the whole day (kJ)
NONDIGFI	Non-digestible forage intake ($g \cdot h^{-1}$)
NITRO	Nitrogen pool in the rumen (g)
NRFP(10)	Non-digestible material in the rumen for each plant group (g)
OLDCC	Cell content in the rumen from the last hour of the previous day (g)
OLDCW	Cell wall in the rumen from the last hour of the previous day (g)
OLDNITRO	Nitrogen in the rumen from the last hour of the previous day (g)
OLDNRFP(10,15)	Non-digestible material for each plant group in the rumen from the last hour of the previous day (g for each of the 15 seasons)
PAWIN	Proportion of feeding time spent cratering
PCMAX(10)	The consumption rate of each plant group forage ($g \cdot min^{-1}$)
PLANT=1	moss
PLANT=2	Lichen
PLANT=3	Mushrooms
PLANT=4	Horsetails
PLANT=5	Graminoids
PLANT=6	Deciduous shrubs
PLANT=7	Evergreen shrubs
PLANT=8	Forbs
PLANT=9	Standing dead material
PLANT=10	Eriophorum heads
PLTBIO	Seasonal available biomass for each forage species ($g \cdot m^{-2}$ live green)
PLTCW	Seasonal values of the proportion of each plant group that is cell wall

PLTDIG(10,15)	Seasonal digestibilities for each plant group (proportion)
PLTDIM	Parameter indicating number of plant groups.
PLTDP(10,15)	Seasonal dietary proportions for each plant group for 15 seasons
PLTNIT	Seasonal values of the proportion of each plant group that is nitrogen (%)
RCAP	Capacity of the rumen (g).
RFILL	Actual amount of forage in the rumen (g)
RUNNIN	Proportion of time spent running
SEASDIM	Array size of seasons
SDAY(15)	The midpoint, in Julien Days, of each of the 15 seasons
STAND	Proportion of time spent standing
TER	The amount of energy yielded from the rumen pools before adding forage ingested in the current hour (kJ)
TFI	Total forage intake over all plant groups ($g \cdot h^{-1}$)
WALK	Proportion of time spent walking
WEIGHT	The metabolic weight of an average female caribou (kg)
WT75	Metabolic weight of the female caribou
Z(MAXDIM1,MAXDIM2)	Array used for plotting the results of simulation.
ZN$(MAXDIM1)	Array storing names of plot variables.

PC SIMULATOR

Version 2.0

by

Fred W. Hovey
(88.03.31)

Background

PC_Simulator (PC_SIM) is a program that makes simulation models easy to use. Among its many useful features is the ability to plot, display, or print the values of key variables at any stage of the simulation. The program was developed at U.B.C. by the author for use with BASIC language compilers. It has its origins with Dr. C.J. Walter's (U.B.C.; Zoology) MICROSIMCON program that was developed in the late seventies for use with Apple micro-computers and INTERPRETATIVE BASIC. In 1985, D. J. Vales (U.B.C.; Forestry) modified MICROSIMCON to make it compatible with IBM PCs. Among the features Vales added were an online help menu and the ability to display plot variable names and data. Those features have been retained and enhanced in PC_SIM.

MICROSIMCON was designed to run in INTERPRETATIVE BASIC; consequently, it is slow. To take advantage of the speed, compactness, and portability of programs generated by compilers I greatly modified MICROSIMCON's code. The program is now structured and modularized. In addition, many new features and error-handling routines that improve the use of simulation models on micros have been added. Those features and changes are detailed in Appendix I.

Operation

PC_SIM begins by asking the user how many iterations (e.g., years or days) the model is to cycle before entering graphics mode (Fig. 1). The user can input any value up to a maximum of 32,737 (2^{15}-1). The program then asks for the names of the data files needed to run the simulation model. In each case, the program provides a default file name that can be chosen simply by pressing the carriage return key, ENTER (indicated as <CR>).

The starting values of certain variables used in the simulation can be set via a special data file called the "set file". That file, like all other data files used by PC_SIM, is external to the program; hence any editor can be used to create or change it. Each line of the set file contains the name and initial value of the variable that is to be set by the program. For example,

caribou weight =,100

would initialize the variable representing caribou weight to a value of 100. In all cases, a comma must appear after, but not before the equals sign ("="). To set the initial values for variable arrays, the numbers must be separated by commas. For example,

caribou numbers (age 1 to 5) =,1000,800,600,500,300

YEAR = 0

Simulation begins at Year: 0
Finish Simulation at Year:? 100

What is the name of the set file (DEFAULT = HARVEST.SET)?

Figure 1. The initial PC_SIM screen. In this example the user has instructed the program to execute the model for 100 iterations (i.e., years).

sets the first element of an array containing the age-specific population of caribou to 1000 and the last element to 300.

Once the data and initial conditions are loaded, the program begins cycling through the model. You can interrupt the progress of the simulation at the end of any cycle or iteration, by pressing any key on the keyboard or by setting the variable "TIMESTOP" in the set file to the desired stop point. This feature is useful for monitoring the progress of the simulation and for changing any of the set or data files. When the program has been interrupted, it asks the user whether they wish to continue the simulation (Fig. 2). Any response (including <CR>) other than a character string beginning with "N"[1] or "n" signifies a yes answer (this command format is common throughout PC_SIM). A NO answer terminates execution of the program. If the user wishes to continue the simulation, the program will ask whether it should enter graphics mode to allow viewing the status of key variables. A NO answer indicates that the user wishes to change the data before continuing the simulation. If the latter answer is chosen the program will ask the user if they wish to change the data in the set file (Fig. 3). A "Y" or "y" will generate the prompt: "Do you wish to read another set file". If the answer is affirmative, the user has the option of changing the set data either by reading another file ("Y" or "y" answer) or by changing the data interactively (<CR>). Before continuing, the program will also ask the user whether to change the other data files used in the simulation.

After an interruption, program execution begins with the iteration following the one at which the model was stopped. To restart the program, the user must enter the number of iterations at which the simulation is to terminate or press enter to take the default value. By repeating the above procedures the user can interrupt the program, view model's output, or alter the data and set files as often as desired.

<u>Graphics</u>

When the program reaches the specified number of iterations, it enters graphics mode (Fig. 4) and allows the user to, among other things, plot the simulation variables. One of the more useful commands in this mode of PC_SIM is the "H" or "HELP" command that generates the help menu. The following is a more detailed description of that menu.

COMMAND	DESCRIPTION
1. <u>C</u>lear	clears the screen and removes any minimum or maximum scaling factors set with either a min or m# command.
2. <u>Q</u>uit	clears the screen and terminates program execution.
3. <u>H</u>elp	prints the help menu on the screen.

1/ Throughout PC_SIM command language, only the first letter of a command needs to be entered. That letter can be in either upper or lower case format.

YEAR = 5

Simulation begins at Year: 0
Finish Simulation at Year:? 100

PRESS ANY KEY TO INTERRUPT PROGRAM
Do you want to continue program execution (<CR> or No)?

Do you want to plot the current results (Yes or <CR>)?

Figure 2. The PC_SIM screen after the program has been interrupted. In this example the user has interrupted the simulation at year 5 and instructed the program to continue execution. The program now asks the user whether to plot the results of the simulation from years 1 through 5.

```
CURRENTLY YEAR = 5


DO YOU WANT TO START OVER (Yes OR <CR>)?
DO YOU WANT TO CHANGE THE VARIABLES IN THE SET FILE (Yes OR <CR>)? y
DO YOU WANT TO READ ANOTHER SET FILE (Yes OR <CR>)?


What is the vulnerability of yearling males (Default = 2)
```

Figure 3. Interactively altering the data during an interruption in program execution. This screen is generated if the user answers no to the last question shown in Fig. 2.

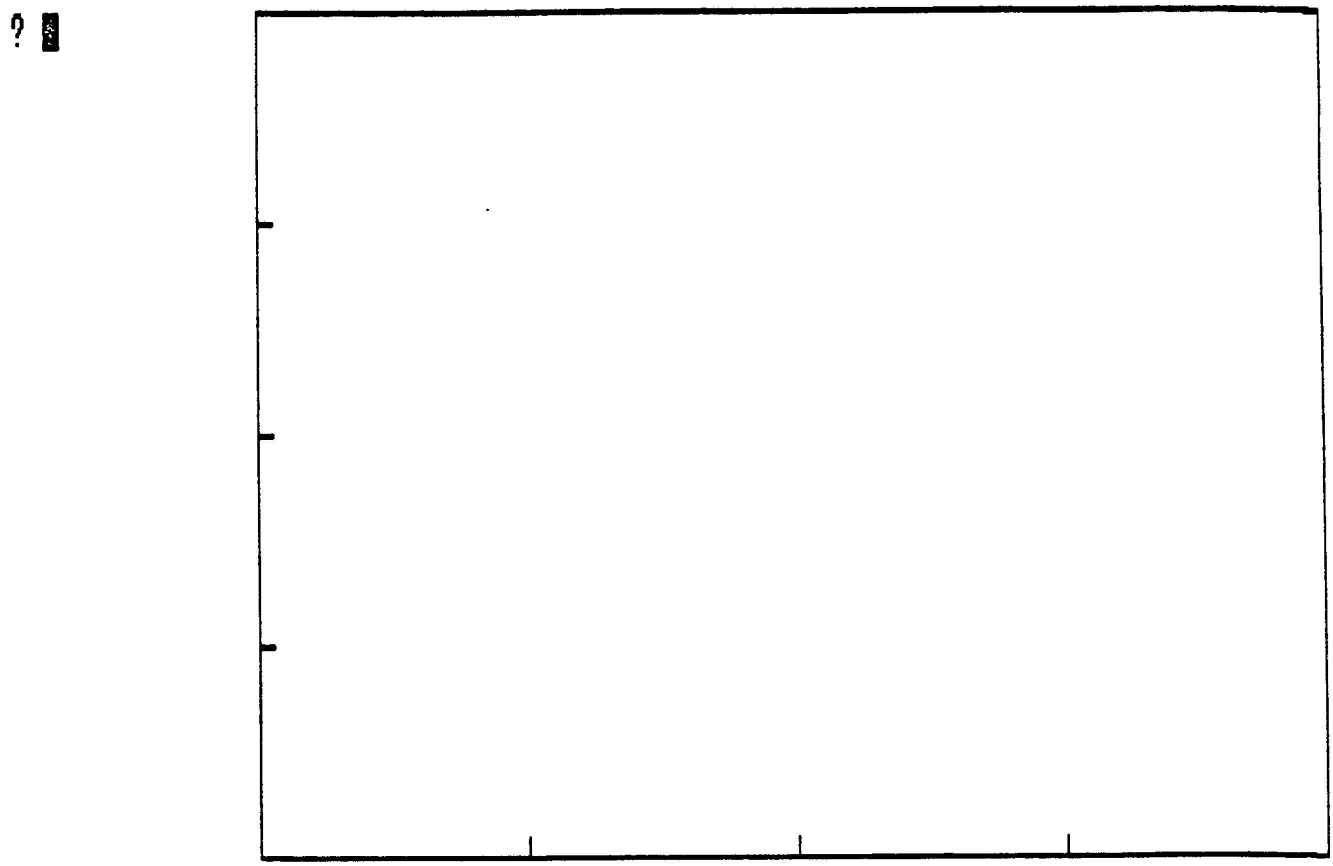

Figure 4. The PC_SIM screen after the program has entered graphics mode

4. Variable list — prints a list of all the variable names and their associated plotting numbers on to the screen.

5. Saves filename — saves the plot exactly as it appears on the screen onto a floppy or hard disk. The plot will be stored in the file specified by filename. That name must follow DOS conventions. If the three letter file extension is not specified, the program appends .BAS to the filename.

   e.g., S a:plotl saves screen onto a floppy disk located in drive A with the name plotl.bas.

6. Restore filename — erases the current screen and then restores the plot from hard memory that has been saved with an "S" command. The program allows additional plotting over the restored plot. With an "S" or "R" command, if the filename is not specified the program will trap the error and allow the user to enter DOS, quit the program, enter a new filename, or cancel the command. Experienced users of PC_SIM will take advantage of this feature when they wish to enter DOS without terminating program execution.

7. Display# — displays the values and associated iteration number for plot variable specified by #.

   e.g., D5 displays values for variable number 5

8. Maximum# — scales all subsequent plots to the maximum specified by #. This scaling factor applies only to those variables that have maximum values less than #.

   e.g., M1000 scales all subsequent plots to a maximum of 1000. This command stays in effect until a C command is issued.

9. MIN — scales all subsequent plots to the minimum value of the plot variable.

10. Write# filename	writes the values for variable # and their corresponding iteration numbers to the file specified by filename.
11. <cr> or Null line	restarts program for another simulation period.
12. #	plots variable # versus time e.g., 5 plots variable number 5
13. #p	plots variable # with unconnected points (scatter plot)
14. 1 vs 2 or 1 2	plots variable 1 versus variable 2 (i.e., 1 on Y axis, 2 on X axis)
15. 1/30 vs 2/100	plots variable 1 versus variable 2 with Y axis scaled to a maximum of 30 and the X axis scaled to a maximum of 100. Note that the "/" overrides any maximums set with the "M#" command (see point 8).
16. 1/30 vs 2p/100	same result as in the preceding example, except a scatter plot is generated instead of a line plot.

See Appendix I for a description of the other features of PC_SIM not included in the help menu.

Appendix I

Changes to MICROSIMCON:

1. The framework for reading data and set files has now been established. In addition to this new feature, for each required data set, the program offers the user the choice of taking a default file name (by simply pressing the return key) or specifying a different one.

2. Without terminating the simulation, the program now identifies and allows the user to correct such inevitable errors as:

   i) specifying an incorrect or non-existent file directory, file name, or DOS path.

   ii) specifying files in which the format of the data is incorrect.

   iii) writing plot or data files to protected disks or to disks with insufficient memory availability.

   iv) hardware or disk problems that prevent proper I/O operations.

3. On detecting an error or during plotting, the program now allows the user to access DOS without terminating simulation execution. Thus, the user now has the ability to edit incorrect data files, examine the file directories, change the default DOS path, etc., or issue any DOS command he wishes (this includes running other programs!) without re-starting the often time consuming simulation.

4. Simulations can now be interrupted at any point either by setting a special variable in the set file to a specified stop time or by pressing any key at the desired moment.

5. Interrupted simulations can be continued or terminated at the discretion of the user. If the user wishes to continue the simulation he can either enter graphics mode to plot the status of selected variables or change any of the data used in the simulation. Set data can be changed either interactively or by requesting a new set file.

6. The value determining the end of the simulation period can be changed before an interrupted simulation is continued.

7. The program now detects the kind of graphics card you are using automatically and then configures graphics arrays accordingly.

8. The labeling of all graphs has been made more readable; variable names, maximums, and minimums are now printed under all plotting situations. In addition, the bug where Y-axis labels containing exponents overwrote the screen during plotting has been corrected.

9. Negative numbers can now be plotted.

10. For variables containing both negative and positive values, the program now draws a "zero" line across the screen.

11. The program now allows the user to set a plot maximum so that all subsequent plots are on the same scale until either a clear command is entered or a new maximum is specified.

12. A bug has been corrected so that the user can now scale any variable independent of the rest to a maximum equal to or greater than the variable's actual maximum. This corrected feature also works when one variable is plotted against the other or when a plot maximum command has been issued.

13. The program now allows the user to set the minimum to which the program scales plots. By default all plots containing positive numbers are scaled from 0 to the maximum value of the data. When the "min" command is issued or when plots contain negative numbers, the program scales the axes from the smallest number to the largest or to the number set by "max" or "/" commands.

14. Values of selected variables indexed by corresponding day or year can now be displayed (100 at a time) for any simulation length (i.e., periods > 100).

15. The printing of variable names is no longer restricted to one screen.

16. More efficient programing structure and variable use has resulted in a saving of approximately 20% of the memory used in plotting.

17. A <u>single</u> simulation period can now extend to 32,767 (2^{15}-1) iterations.

18. After the user has finished plotting, the program now allows one the choice of either terminating the program or continuing the simulation. If the user decides to continue the simulation, he can either start over (i.e., re-initialize) or continue with the values the simulation terminated with. If the latter choice is exercised repeatedly, the user can theoretically simulate the chosen conditions for periods limited only by his patience. As with interrupted simulations, simulations following graphics mode also allow the user the option of changing any of the data or set files. If the user does not exercise the option of changing the end time, the simulation will, by default, finish after the same number of iterations as the previous simulation.