Conifer: A Model of Carbon and Water Flow through a Coniferous Forest

Documentation

Coniferous Forest Biome Modeling Group

Bulletin No. 8 • Coniferous Forest Biome Ecosystem Analysis Studies

CONIFER: A MODEL OF CARBON AND WATER FLOW THROUGH A CONIFEROUS FOREST

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ABSTRACT

CONIFER simulates water, carbon, and energy dynamics of a coniferous forest. The model consists of 29 nonlinear difference equations. Driving variables include air temperature, dew point temperature, precipitation, solar radiation, and wind speed. Water and energy variables are updated daily; carbon variables are updated weekly. This report contains a detailed description of the model including all equations, parameter values, and initial conditions. Cross-reference tables list the equations in which each variable and parameter appear. Listings of the driving variable data, computer implementation, and corresponding output are also provided. Information sources and model behavior are discussed elsewhere.

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1. INTRODUCTION

In this report we present documentation for CONIFER, a model of water and carbon flow through a coniferous forest. We have tried to provide in this report all the information needed to implement the model on a computer and to obtain output. The report is intended for ecologists with interest in specific details of the model, for the programmer or ecologist interested in implementing the model, and for those of us in our own project who work with CONIFER.

Only a description of the model is provided herein. The ecological assumptions, sources from which parameters were calculated, and behavior of the model are discussed elsewhere (Sollins et al. 1974, Edmonds and Sollins 1974, P. Sollins and G. L. Swartzman MS in prep.). The old-growth forest ecosystem on which CONIFER is based is described by Grier and Logan (in press) and P. Sollins, C. C. Grier, K. Cromack, F. Glenn, and R. Fogel (MS submitted).

This report supersedes an undated internal report (no. 158) of the Coniferous Forest Biome by G. Swartzman and P. Sollins entitled "Documentation for a combined carbon-water flow stand level coniferous forest model."

1.1. *Format of the Report and Definitions*

The format of this report follows closely that of the FLEXFORM described by White and Overton (1974).

Model variables are restricted to six types: state variables, timing variables, driving variables, flow variables, intermediate variables, and output variables. In addition, there are special functions, two sets of parameters, and a set of initial conditions. Mnemonic variable names are not used. The abbreviation *(dim.)* indicates that the parameter or variable is dimensionless.

Driving variables (denoted Z_i) are those factors extrinsic to the system whose values influence the system but are not themselves influenced by it. Examples are average daily air temperature (Z_3) and daily amount of precipitation (Z_1). *State variables* (denoted X_i) consist of that set of variables whose values summarize the present state of the system and that are sufficient to predict the future state of the system when used as initial conditions in equations that describe the rate of change of each state variable. State variables in this model correspond primarily to storages in compartments, for example, amount of carbon in old foliage (X_{11}) or amount of water stored in the litter (X_7). *Flow variables* (denoted $F[i,j]$) correspond to the amount of a particular material transferred between two compartments during a time interval. This is calculated in a corresponding flow function, which in general may depend on state variables or driving variables or any parameters but not on other flow variables. In cases in which several flow functions have terms in common we create an *intermediate variable* (denoted G_i) and write both flows as functions of the intermediate variable.

The use of intermediate variables (*G* functions) helps make clear the interactions between processes. For example, foliage resistance (stomatal) resistance plus mesophyll resistance) is used directly in the photosynthesis flow function and indirectly (after dividing by leaf area index to obtain a canopy resistance) in the transpiration flow function. The appearance of the same *G* function in both a water and a carbon flow function makes clear a coupling--an important structural feature of both the model and the systam.

It should be noted that in CONIFER for every flow function there is a corresponding *G* function to which the *F* function is equal. This is not a required feature of the paradigm but rather a practice we have found convenient.

Output variables (denoted Y_i) are created to display aspects of model behavior that cannot be seen by printing or plotting *X* variables, *F*'s, or *G*'s. These variables do not appear in *F*, *G*, or *Z* functions and do not influence system behavior. Examples include changing the units of, say, a *G* function such as resistance to conductance for comparison with published values. In our model, for example, we have a *Y* variable for net weekly assimilation (Y_{15}), which is the sum of old and new foliage net daytime photosynthesis less the sum of old and new foliage nighttime respiration.

Within many *G* functions *temporary variables* are used to simplify calculations. These temporaries are denoted T_1, T_2, etc. in the code and are never used to transfer information from one *G* function to another.

1.2. *Model Structure*

An overview of the model structure is necessary to avoid mistaking the forest for the trees. Three basic cycles are considered (Figure 1): water, carbon, and energy. The law of conservation of mass is used in the carbon and water modules in that all material entering the system either accumulates or flows out. In the energy module we have not maintained a conservation scheme, choosing instead to model only those processes we felt were important.

Unfortunately, flow diagrams as such provide no information about interactions among carbon, water, and energy flow processes, much less about interactions among processes within a module. Various attempts have been made to provide this information diagrammatically (e.g., Forrester 1971), but none is workable for a model as large and complex as CONIFER. We feel that some discussion of interactions is essential and have included in this section a list of those variables (*X*'s and *G*'s) that influence processes outside the module in which they are calculated (Table 1). Thus, for example, all cases in which a carbon variable affects water flow processes are listed. Other details of interactions between processes can be found in the detailed descriptions of each *G* function and in tree diagrams, which specify exhaustively the sequence of computation of all *G*'s.

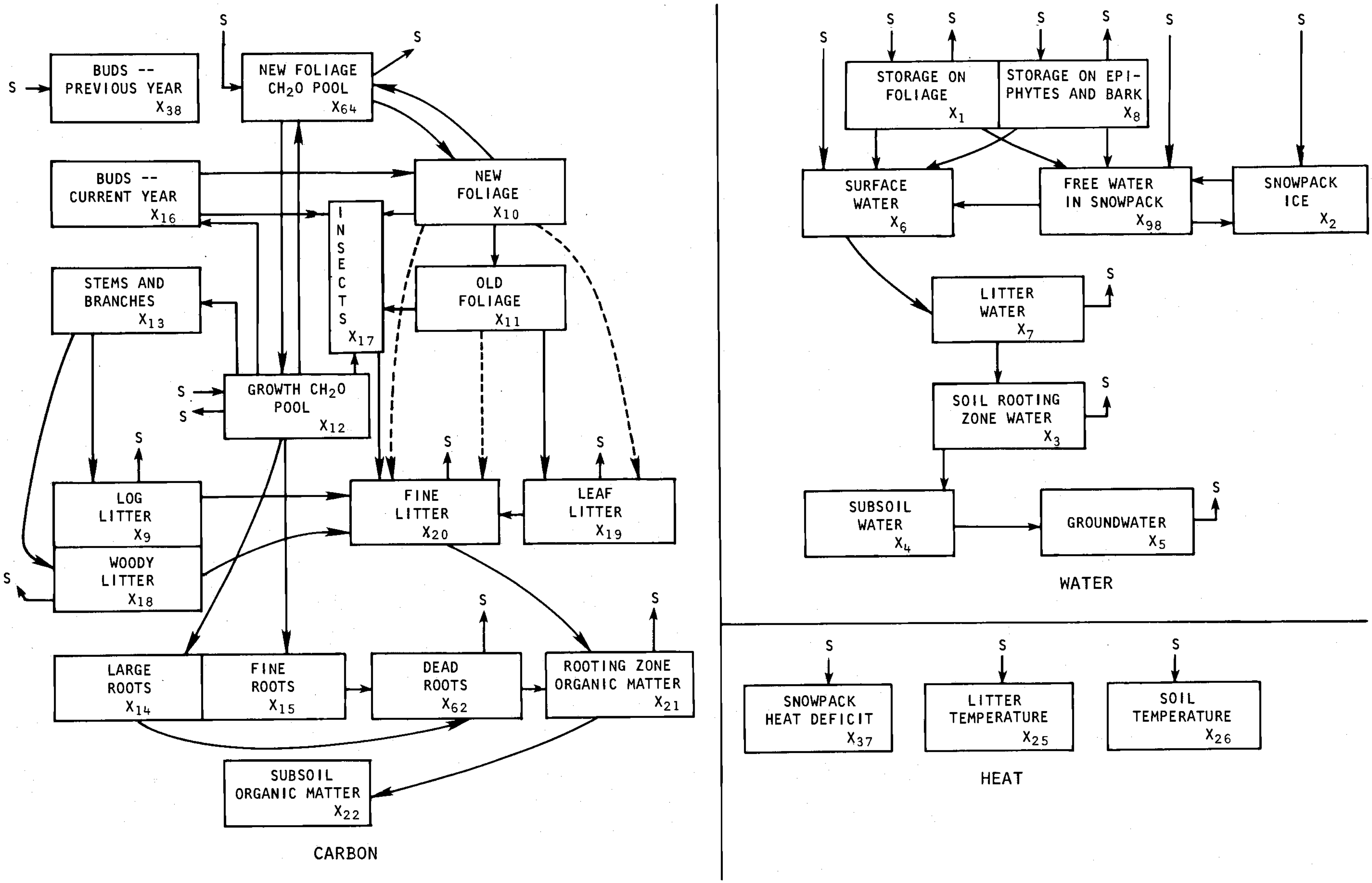

Figure 1. Compartments and flows of CONIFER. Dashed lines indicate transfers occurring only during perturbations.

Table 1. Interactions among modules of CONIFER.

Effect of carbon variables on water and energy flows	*Comments*
A. *Foliage biomass affects:*	
1. Transpiration	
2. Fraction of rain incident to canopy that strikes foliage (and therefore also fraction striking nonfoliage)	2. This and following two affect drip, litter, and soil moisture dynamics. There are also indirect effects through percent cover.
3. Water retention capacity of canopy	
4. Distribution of retention capacity between foliage and nonfoliage	
5. Fraction of rainfall passing directly to forest floor	5. Through percent cover
6. Net longwave radiation input to canopy	6. Through percent cover, which affects input and loss
B. *Stem biomass affects:*	
1. Percent cover (and therefore numbers 2-6 above)	
C. *Fine, leaf and woody litter mass affects:*	
1. Water retention capacity of litter	
Effect of water variables on carbon and energy flows	
A. *Soil moisture affects:*	
1. New and old foliage photosynthesis	1. Via stomatal resistance
2. Fine root death	2. Via plant moisture stress
3. Dead root + soil organic matter decomposition processes	
B. *Litter moisture affects:*	
1. Litter decomposition processes	
C. *Snowpack ice affects:*	
1. Litter temperature	
D. *Snowfall affects:*	
1. Heat loss from snowpack due to snowfall	
2. Albedo of snowpack	
E. *Drip plus direct rainfall affect:*	
1. Litter and soil temperature	
Effect of energy variables on carbon and water flows	
A. *Heat input to canopy affects:*	
1. Potential evaporation from canopy	
2. Transpiration	
B. *Litter temperature affects:*	
1. Litter decomposition processes	
2. Potential evaporation from litter	
C. *Soil temperature affects:*	
1. Large and fine root respiration and growth	
D. *Net heat input to snowpack and heat deficit of snowpack affect:*	
1. Net transfer between free water and ice in snowpack	

1.3. *Model Implementation--A Word about SIMCOMP*

CONIFER was implemented on a CDC 6400 at the University of Washington using a flow-oriented simulation language called SIMCOMP. SIMCOMP was designed and built by George Gustafson of the Grasslands Biome, U.S./IBP, and is described in a user's manual, available as Technical Report 138 from the Grasslands Biome, Natural Resource and Ecology Laboratory, Colorado State University, Fort Collins, Colorado. We provide below some details concerning the operation of SIMCOMP although there should be no problem coding CONIFER directly in a higher level language such as FORTRAN.

The SIMCOMP processor uses the following order of computation. SIMCOMP first calls a routine called CYCL1. We use this routine to convert the basic time variable (daily, zero origin) to weekly and monthly time (subroutine TIMER), read in values for the driving variables (subroutine ZUP), and then to calculate the values of each of the *G* functions in the proper order (subroutine GUP).

At the beginning of subroutine GUP, before any *G*'s are calculated, we set all *G*'s equal to a very large number. This ensures that, if a *G* variable is used before it is calculated, an overflow occurs and the program stops executing. This feature immediately brings attention to any circularities and sequencing errors, and we strongly recommend that it be programmed into any future version of the code.

After CYCL1 is complete SIMCOMP calculates the *F* functions using current values of *Z*'s, *G*'s, and *X*'s, and then updates the *X*'s. Thus:

$$X_i(t) = X_i(t-1) + \sum_{\substack{j=1 \\ j \neq i}}^{n} F_{ji} - \sum_{\substack{j=1 \\ j \neq i}}^{m} F_{ij}$$

SIMCOMP next calls CYCL2, which we use only to update *Y* variables.

SIMCOMP may be requested to print or plot in any combination or order *S*, *F*, or *Z* functions or *X* or *Y* variables. This occurs immediately after CYCL2 is completed.

2. STATE VARIABLES

In this section we have listed the state variables (*X*'s) in numerical order. Following the description of each *X* is a list of the *G* functions in which that *X* is used. On the extreme right-hand side are two sets of initial conditions for each *X*. The first corresponds to day 1 in 1972, the second to day 131 in 1972. It should be noted that the first set is simpler in that the initial conditions for X_{10} (new foliage) and X_{38} (bud carbon--last year's) are both zero, while on day 131 these must have nonzero values. The meteorological station did not begin operation until day 131 (see Appendix III) so that for most purposes it is necessary to begin the model on day 131. There is, however, an advantage in starting during the summer in that both X_1 (water stored on foliar surfaces) and X_8 (storage on bark and epiphyte surfaces) can be assumed to be zero.

Two compartments, X_6 and X_{64}, are intended to be zero-valued throughout the simulation. The equations for flows in and out of these compartments are such that the compartment is empty at the end of each time step. These two variables (and X_{22}) are different from all other state variables in that they do not appear in any G functions; they could be eliminated from the model but doing so would increase considerably the complexity of several of the G functions.

		Day 1	Day 131
X_1	water storage on foliage (m^3/ha) -- G_5, G_7, G_{20}, Y_{18}	19.1	0
X_2	snowpack ice (m^3/ha) -- G_{60}, G_{67}, G_{118}, G_{121}, G_{161}	2100	0
X_3	soil rooting zone water (m^3/ha) -- G_{12}, G_{20}, G_{42}, G_{50}, Y_{15}	3208	2960
X_4	subsoil water (m^3/ha) -- G_{19}	10,021	9970
X_5	groundwater storage (m^3/ha) -- G_{18}	0	0
X_6	water storage on litter surface (m^3/ha)	0	0
X_7	litter water (m^3/ha) -- G_{15}, G_{22}, G_{69}, Y_{14}		129.5
X_8	water storage on epiphytes and bark surfaces (m^3/ha) -- G_8, G_{56}, Y_{19}	21.1	0
X_9	log litter carbon (t/ha) -- G_{105}	27.6	28.9
X_{10}	new foliage carbon (t/ha) -- G_{24}, G_{25}, G_{34}, G_{38}, G_{46}, G_{61}, G_{101}, G_{135}	0	0.3183
X_{11}	old foliage carbon (t/ha) -- G_{29}, G_{30}, G_{40}, G_{61}, G_{90}, G_{93}, G_{101}	4.85	4.554
X_{12}	carbon in growth CH_2O pool (t/ha) -- G_{30}, G_{35}, G_{36}, G_{37}, G_{45}, G_{94}, G_{138}, G_{139}, G_{140}	11.3	15.45
X_{13}	stem plus branch carbon (t/ha) -- G_{13}, G_{16}, G_{23}, G_{57}, G_{62}, G_{92}	263.1	261.12
X_{14}	large root carbon (t/ha) -- G_{86}	74.0	73.85
X_{15}	fine root carbon (t/ha) -- G_{87}, G_{140}	4.85	4.813
X_{16}	bud carbon (current year; t/ha) -- G_{44}, G_{79}, G_{95}	0.0125	0.555×10^{-16}
X_{17}	canopy insect carbon (t/ha) -- G_{82}	0.07	0.0374
X_{18}	woody litter carbon (t/ha) -- G_{55}, G_{83}	15.0	15.19
X_{19}	foliage litter carbon (t/ha) -- G_{55}, G_{81}	11.0	10.97

		Day 1	Day 131
X_{20}	fine litter carbon (t/ha) -- G_{55}, G_{84}	13.4	13.43
X_{21}	carbon in soil rooting zone organic matter (t/ha) -- G_{88}	33.3	33.28
X_{22}	carbon in subsoil organic matter (t/ha)	78.0	78.13
X_{25}	litter temperature (deg) -- G_{14}, G_{41}, G_{67}, G_{68}, G_{121}	7.5	7.5
X_{26}	soil rooting zone temperature (deg) -- G_{51}, G_{68}	4.1	4.1
X_{37}	snowpack heat deficit (ly) -- G_{128}, G_{129}, G_{161}	0	0
X_{38}	bud carbon (previous year; t/ha) -- G_{44}, G_{46}	0	0.01249
X_{62}	dead root carbon (t/ha) -- G_{85}	6.0	6.197
X_{64}	carbon in new foliage CH_2O pool (t/ha)	0	0
X_{98}	free water in snowpack (m^3/ha) -- G_{10}, G_{128}, G_{161}	0	0

3. TIMING VARIABLES

In this section we discuss the timing variables (t_d and t_w) used in CONIFER. Definitions of these and lists of their occurrence follow.

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t_d = time in days

Comment: Various functions are set up such that t_d must be day of the year, that is t_d = 1 must be 1 January of some year. We typically begin simulations with t_d = 131, which is the day in 1972 on which the meteorological station began operating. Here t_d is used in special functions S_3, S_5, S_6, and in intermediate function G_{123}.

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t_w = time in weeks (modulo 52)

Comment: This variable gives the week of the year (1-52) and is reset to 1 at the beginning of each year. Day 131 occurs during week 18. Here t_w is used in the following intermediate functions: G_{34}, G_{40}, G_{44}, G_{79}, G_{106}.

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4. DRIVING VARIABLES

In this section we list the driving variables (Z's) used in CONIFER. Immediately following the description of each Z, we list the functions

(G's, S's, and Y's) in which the Z is used. All Z's are averages or totals for a day. The data currently used in running CONIFER are shown in Appendix III. Methods used in obtaining this data set are described by Waring et al. (in press).

Z_1 total precipitation ($m^3 \cdot ha^{-1} \cdot day^{-1}$) -- G_{54}, G_{115}, Y_4

Z_2 average shortwave radiation (ly/min)--- G_{59}, G_{109}, G_{123}

Z_3 average 24-hr air temperature (deg) -- G_{14}, G_{17}, G_{21}, G_{42}, G_{48}, G_{114}, G_{117}, G_{122}, G_{170}

Z_4 day length -- G_6, G_{20}, G_{54}, G_{59}, G_{110}

Z_5 average 24-hr dew point temperature (deg) -- G_2, G_{14}, G_{99}

Z_6 average daytime temperature (deg) -- G_{54}, G_{107}, G_{118}

Z_7 average nighttime temperature (deg) -- G_{54}, G_{108}

Z_{14} average wind speed (m/sec) -- G_{100}

5. FLOW FUNCTIONS

In this section we list the flow functions (F's) used in CONIFER. After each flow, we list the description of that flow, and, on the extreme left, the G function to which the flow is equal. The F's are listed in numerical order except that the index "99" is treated as a "0." This arrangement causes all inputs to the system to appear first.

The flow functions represent terms in the difference equations describing the daily change in each state variable. The abbreviation "$F(10,11)$" indicates transfer from X_{10} to X_{11}; $F(99,10)$ indicates transfer into X_{10} from outside the system, while $F(10,99)$ indicates transfer from X_{10} to outside the system. The difference equation for X_{10}, for example, consists of the sum of all F's containing "10" as the second index [$F(i,10)$] less the sum of all F's containing "10" as the first index [$F(10,j)$]. All flows are calculated daily; however, the G functions from which the carbon flows are calculated are set to zero except every seventh day, in keeping with the weekly time-step of that part of the model.

$F(99,1)$ rain input to foliar surfaces -- G_3

$F(99,2)$ precipitation as snow -- G_{115}

$F(99,6)$ rainfall passing directly to litter surface water -- G_{70}

$F(99,8)$ rain input to bark and epiphyte surfaces -- G_4

$F(99,12)$ input from old foliage photosynthesis to growth CH_2O pool -- G_{29}

$F(99,20)$ input to fine litter from microparticulate matter and carbon dissolved in precipitation -- G_{97}

$F(99,25)$ change in litter temperature -- G_{67}

$F(99,26)$ change in soil temperature -- G_{68}

$F(99,37)$	net increase in heat deficit of snowpack -- G_{128}
$F(99,38)$	change in last year's bud carbon -- G_{44}
$F(99,64)$	input to new foliage CH_2O pool due to net new foliage photosynthesis -- G_{24}
$F(99,98)$	rainfall passing directly into free water in snowpack -- G_{74}
$F(1,99)$	evaporation from foliage -- G_7
$F(1,6)$	drip from foliage to litter surface -- G_{71}
$F(1,98)$	drip from foliage to free water in snowpack -- G_{75}
$F(2,98)$	transfer from ice to free water in snowpack -- G_{129}
$F(3,99)$	transpiration rate -- G_{20}
$F(3,4)$	water transfer from soil rooting zone to subsoil -- G_{12}
$F(4,5)$	water transfer from subsoil to groundwater -- G_{19}
$F(5,99)$	outflow from groundwater -- G_{18}
$F(6,7)$	water flow from surface into litter layer -- G_{11}
$F(7,99)$	evaporation from litter -- G_{22}
$F(7,3)$	water transfer from litter to soil rooting zone -- G_{15}
$F(8,99)$	evaporation from epiphyte and bark surfaces -- G_8
$F(8,6)$	water drip from epiphyte and bark surfaces to storage on litter surface -- G_{72}
$F(8,98)$	drip from epiphyte and bark surfaces to free water in snowpack -- G_{76}
$F(9,99)$	carbon loss from logs due to respiration -- G_{113}
$F(9,20)$	carbon loss from logs due to fragmentation -- G_{112}
$F(10,11)$	maturation of new foliage -- G_{34}
$F(10,17)$	new foliage consumption by insects -- G_{38}
$F(10,19)$	carbon transfer from new foliage to leaf litter due to acute defoliation -- G_{135}
$F(10,20)$	carbon transfer from new foliage to fine litter due to acute defoliation -- G_{135}
$F(10,64)$	carbon transfer from new foliage to new foliage CH_2O pool -- G_{27}
$F(11,17)$	old foliage consumption by insects -- G_{90}
$F(11,19)$	transfer from old foliage to leaf litter due to leaf fall and acute defoliation -- G_{40}
$F(11,20)$	transfer from old foliage to fine litter due to acute defoliation -- G_{136}
$F(12,99)$	total respiration loss from growth CH_2O pool -- G_{31}
$F(12,13)$	carbon transfer to stems plus branches -- G_{35}
$F(12,14)$	carbon transfer to large roots -- G_{36}

$F(12,15)$ carbon transfer to fine roots -- G_{37}

$F(12,16)$ bud growth -- G_{33}

$F(12,17)$ consumption of growth CH_2O pool by insects -- G_{94}

$F(12,64)$ transfer of carbon from growth CH_2O pool to new foliage CH_2O pool to meet foliar respiration and growth demands -- G_{32}

$F(13,9)$ carbon transfer from stems plus branches to log litter -- G_{62}

$F(13,18)$ carbon transfer from stems plus branches to woody litter -- G_{92}

$F(14,62)$ large root mortality -- G_{86}

$F(15,62)$ fine root mortality -- G_{87}

$F(16,10)$ carbon transfer from buds to new foliage -- G_{79}

$F(16,17)$ bud consumption by insects -- G_{95}

$F(17,20)$ insect frass input to fine litter -- G_{82}

$F(18,99)$ carbon loss from woody litter due to respiration -- G_{111}

$F(18,20)$ carbon loss from woody litter due to fragmentation -- G_{104}

$F(19,99)$ carbon loss from foliage litter due to respiration -- G_{103}

$F(19,20)$ carbon loss from foliage litter due to fragmentation -- G_{98}

$F(20,99)$ carbon loss from fine litter due to respiration -- G_{125}

$F(20,21)$ incorporation of fine litter into rooting zone organic matter -- G_{116}

$F(21,99)$ carbon loss from rooting zone due to respiration -- G_{133}

$F(21,22)$ carbon transfer from soil rooting zone to subsoil -- G_{132}

$F(62,99)$ carbon loss from dead roots due to respiration -- G_{131}

$F(62,21)$ carbon loss from dead roots due to fragmentation -- G_{126}

$F(64,99)$ new foliage nighttime respiration -- G_{25}

$F(64,10)$ transfer of carbon to new foliage from new foliage CH_2O pool -- G_{26}

$F(64,12)$ transfer of surplus carbon from new foliage CH_2O pool to growth CH_2O pool -- G_{28}

$F(98,2)$ transfer from free water in snowpack to ice -- G_{161}

$F(98,6)$ water draining from snowpack to litter surface -- G_{10}

6. INTERMEDIATE VARIABLES AND FUNCTIONS

In this section we list the intermediate variables (*G*'s) and the corresponding functions used in CONIFER. The section contains three parts. The first is a cross-reference list designed to provide some minimum information about each *G* quickly. It contains the description of each *G* followed by a list of *G* and *Y* (output) functions in which the *G* is used.

The second part provides algebraic and English language descriptions of each G. All variables and constants used in the G function are defined. A "comment" paragraph may provide information helpful in understanding how the G function behaves. In several cases involving rather complicated or nonlinear functions the comments include graphs of the G plotted against the variables upon which it depends. Both lists are in numerical order, and not in order of computation.

In the third part, we show the scheme we used to divide the G's into modules, the order in which the modules occur, and the sequence of computation within each module. The G functions pertinent to computing water flow through the system are calculated each day. The G functions used only in calculating carbon transfers are zero-valued except every seventh day. Variables that occur in modules 1 through 8 are calculated daily while those occurring in modules 9 through 18 are calculated weekly.

6.1. *Cross-Reference Listing of Intermediate Variables*

G_1 one-sided needle surface area index -- G_{20}

G_2 heat input to snowpack due to condensation -- G_{127}

G_3 rain input to foliar surfaces -- $F(99,1)$, G_5, G_7, G_{20}

G_4 rain input to epiphyte and bark surfaces -- $F(99,8)$, G_8, G_{56}

G_5 drip from foliar surfaces -- G_7, G_{20}, G_{71}, G_{75}, G_{134}

G_6 potential evaporation from canopy -- G_5, G_7, G_8, G_{56}

G_7 evaporation from foliar surfaces -- $F(1,99)$, G_{20}, Y_1

G_8 evaporation from epiphyte and bark surfaces -- $F(8,99)$, Y_1

G_9 rainfall passing directly to snowpack or litter surface -- G_{70}, G_{74}, G_{134}

G_{10} water transfer from snowpack to litter surface -- $F(98,6)$, G_{11}

G_{11} water entering litter -- $F(6,7)$, G_{15}, G_{22}

G_{12} water transfer from soil rooting zone to subsoil -- $F(7,3)$, G_{19}

G_{13} fraction of rain incident to canopy, which strikes foliage -- G_3, G_4

G_{14} potential evaporation from litter -- G_{15}, G_{22}

G_{15} water transfer from litter to soil rooting zone -- $F(7,3)$, G_{12}

G_{16} water retention capacity of canopy -- G_5, G_{56}

G_{17} rate of change of saturation vapor pressure with temperature -- G_6, G_{20}

G_{18} outflow from groundwater -- $F(5,99)$

G_{19} water transfer from subsoil to groundwater -- $F(4,5)$

G_{20} transpiration rate -- $F(3,99)$, G_{12}, Y_2

G_{21} saturation vapor pressure at air temperature -- G_{17}, G_{99}

G_{22} evaporation from litter -- $F(7,99)$, Y_1

G_{23} percent cover by canopy (also percent cover by overstory) -- G_3, G_4, G_9, G_{91}, G_{120}, G_{124}, G_{168}

G_{24} net new foliage photosynthesis -- $F(99,64)$, G_{47}, Y_9, Y_{16}

G_{25} new foliage nighttime respiration -- $F(64,99)$, G_{47}, Y_9, Y_{11}, Y_{16}

G_{26} transfer of carbon to new foliage from new foliage CH_2O pool -- $F(64,10)$, G_{34}

G_{27} transfer of carbon from new foliage to new foliage CH_2O pool -- $F(10,64)$, G_{34}

G_{28} transfer of surplus carbon from new foliage CH_2O pool to growth CH_2O pool -- $F(64,12)$

G_{29} net old foliage photosynthesis -- $F(99,12)$, Y_{10}, Y_{16}

G_{30} old foliage nighttime respiration -- G_{78}, Y_{10}, Y_{16}

G_{31} total respiration loss from growth CH_2O pool -- $F(12,99)$, Y_{11}

G_{32} transfer of carbon from growth CH_2O pool to new foliage pool to meet foliar respiration and growth demands -- $F(12,64)$

G_{33} bud growth -- $F(12,16)$, G_{79}

G_{34} maturation of new foliage -- $F(10,11)$

G_{35} carbon transfer to stems and branches -- $F(12,13)$

G_{36} carbon transfer to large roots -- $F(12,14)$

G_{37} carbon transfer to fine roots -- $F(12,15)$

G_{38} new foliage consumption by insects -- $F(10,17)$, G_{34}, G_{44}

G_{39} temperature effect on growth processes -- G_{33}, G_{35}, G_{38}, G_{46}, G_{90}, G_{94}, G_{95}

G_{40} leaf-fall rate -- $F(11,19)$

G_{41} litter temperature -- G_{77}

G_{42} plant moisture stress (PMS) -- G_{43}, G_{87}

G_{43} new foliage stomatal resistance -- G_{49}, G_{52}, G_{101}

G_{44} change in last year's bud carbon -- $F(99,38)$, G_{46}

G_{45} portion of growth CH_2O pool available for foliar respiration and growth -- G_{26}, G_{27}, G_{28}, G_{32}

G_{46} new foliage growth demand -- G_{26}, G_{28}, G_{32}

G_{47} surplus or deficit of new foliage photosynthate after new foliage respiration is satisfied -- G_{26}, G_{27}, G_{28}, G_{32}

G_{48} average weekly 24-hr air temperature -- G_{39}, G_{41}, G_{138}

G_{49} average weekly stomatal resistance of new foliage -- G_{24}

G_{50} effect of moisture and temperature on soil rooting zone processes -- G_{85}, G_{88}

G_{51} weekly average soil temperature -- G_{53}, G_{139}, G_{140}

G_{52} stomatal resistance of old foliage -- G_{58}, G_{101}

G_{53} effect of soil temperature on soil processes -- G_{36}, G_{37}, G_{50}

G_{54} precipitation as rain -- G_{3}, G_{4}, G_{9}, G_{115}

G_{55} water holding capacity of litter -- G_{15}, G_{22}, G_{69}, Y_{14}

G_{56} drip from epiphyte and bark surfaces -- G_{8}, G_{72}, G_{76}, G_{134}

G_{57} fraction of water retention capacity of canopy due to foliage -- G_{5}, G_{7}, G_{8}, G_{56}

G_{58} average weekly stomatal resistance of old foliage -- G_{29}

G_{59} net shortwave radiation at top of canopy -- G_{91}, G_{169}, Y_{17}

G_{60} snowpack ice plus current day's snowfall -- G_{5}, G_{10}, G_{11}, G_{70}, G_{71}, G_{72}, G_{74}, G_{76}, G_{128}, G_{129}, G_{130}, G_{161}

G_{61} total foliage carbon -- G_{1}, G_{13}, G_{16}, G_{24}, G_{29}, G_{57}, G_{91}, G_{101}

G_{62} carbon transfer from stems plus branches to log litter -- $F(13,9)$

G_{67} change in litter temperature -- $F(99,25)$

G_{68} change in soil temperature -- $F(99,26)$

G_{69} effect of moisture and temperature on litter processes -- G_{81}, G_{83}, G_{84}

G_{70} rainfall passing directly to litter surface water -- $F(99,6)$

G_{71} drip from foliar surfaces to litter surface water -- $F(1,6)$

G_{72} drip from epiphyte and bark surfaces to litter surface water -- $F(8,6)$, G_{76}

G_{74} rainfall passing directly to free water in snowpack -- $F(99,98)$, G_{10}

G_{75} drip from foliar surfaces to free water in snowpack -- $F(1,98)$, G_{10}

G_{76} drip from epiphyte and bark surfaces to free water in snowpack -- $F(8,98)$

G_{77} effect of temperature on litter processes -- G_{69}, G_{105}

G_{79} carbon transfer from buds to new foliage -- $F(16,10)$

G_{80} total weekly direct rainfall plus drip -- G_{67}

G_{81} foliage litter decomposition rate -- G_{98}, G_{103}

G_{82} insect frass input to fine litter -- $F(17,20)$

G_{83} woody litter decomposition rate -- G_{104}, G_{111}

G_{84} fine litter decomposition rate -- G_{116}, G_{125}

G_{85} dead root decomposition rate -- G_{126}, G_{131}

G_{86} large root mortality -- $F(14,62)$

G_{87} fine root mortality -- $F(15,62)$

G_{88} rooting-zone organic matter decomposition rate -- G_{132}, G_{133}

G_{90} old foliage consumption by insects -- $F(11,17)$

G_{91} shortwave radiation incident to snowpack or litter -- G_{119}, Y_{17}

G_{92} carbon transfer from stems plus branches to woody litter -- $F(13,18)$

G_{93} acute old-foliage defoliation -- G_{40}, G_{136}

G_{94} consumption of growth CH_2O pool by insects -- $F(12,17)$

G_{95} bud consumption by insects -- $F(16,17)$, G_{79}

G_{97} input to fine litter from microparticulate matter and carbon dissolved in precipitation -- $F(99,20)$

G_{98} carbon loss from foliage litter due to fragmentation -- $F(19,20)$

G_{99} vapor pressure deficit -- G_6, G_{20}

G_{100} aerodynamic resistance -- G_6, G_{20}

G_{101} canopy resistance -- G_{20}

G_{102} effect of temperature on photosynthesis -- G_{24}, G_{29}

G_{103} carbon loss from foliage litter due to respiration -- $F(19,99)$, Y_6, Y_{12}

G_{104} carbon loss from woody litter due to fragmentation -- $F(18,20)$

G_{105} log litter decomposition rate -- G_{112}, G_{113}

G_{106} phenology of tree growth -- G_{33}, G_{35}, G_{44}

G_{107} average weekly daytime air temperature -- G_{102}

G_{108} average weekly nighttime air temperature -- G_{25}, G_{30}

G_{109} average weekly photosynthetically active radiation -- G_{24}, G_{29}

G_{110} average weekly day length -- G_{24}, G_{25}, G_{29}, G_{30}

G_{111} carbon loss from woody litter due to respiration -- $F(18,99)$, Y_6, Y_{12}

G_{112} carbon loss from logs due to fragmentation -- $F(9,20)$

G_{113} carbon loss from logs due to respiration -- $F(9,99)$, Y_6, Y_{12}

G_{114} heat input to snowpack due to snowfall -- G_{127}

G_{115} precipitation as snow -- $F(99,2)$, G_{60}, G_{114}, G_{118}, Y_5

G_{116} incorporation of fine litter into rooting zone organic matter -- $F(20,21)$

G_{117} heat input to snowpack due to rainfall -- G_{127}

G_{118} albedo of snowpack or litter -- G_{119}

G_{119} net heat transfer through canopy to snowpack or litter due to shortwave radiation -- G_{127}, G_{169}

G_{120} net heat input to snowpack or litter due to longwave radiation -- G_{127}

G_{121} heat loss from snowpack or litter due to longwave radiation -- G_{120}, G_{124}

G_{122} longwave radiation from blackbody at air temperature -- G_{123}, G_{124}, G_{168}

G_{123} longwave radiation from sky -- G_{120}, G_{168}

G_{124} net heat transfer from canopy to snowpack or litter due to longwave radiation -- G_{120}, G_{169}

G_{125} carbon loss from fine litter due to respiration -- $F(20,99)$, Y_6, Y_{12}

G_{126} carbon loss from dead roots due to fragmentation -- $F(62,21)$

G_{127} net heat input to snowpack -- G_{118}, G_{128}, G_{129}, G_{161}

G_{128} net increase in heat deficit of snowpack -- $F(99,37)$

G_{129} transfer from ice to free water in snowpack -- $F(2,98)$, G_{10}

G_{130} free water holding capacity of snowpack -- G_{10}

G_{131} carbon loss from dead roots due to respiration -- $F(62,99)$, Y_7, Y_{12}

G_{132} carbon transfer from soil rooting zone to subsoil -- $F(21,22)$

G_{133} carbon loss from rooting zone organic matter due to respiration -- $F(21,99)$, Y_7, Y_{12}

G_{134} total water input to snowpack or litter -- G_{11}, G_{80}, G_{117}, G_{128}, G_{161}

G_{135} transfer from new foliage to leaf litter due to acute defoliation -- $F(10,19)$, $F(10,20)$

G_{136} carbon transfer from old foliage to fine litter due to acute defoliation -- $F(11,20)$

G_{138} stem-plus-branch respiration -- G_{31}

G_{139} large root respiration -- G_{31}, Y_7, Y_{12}

G_{140} fine root respiration -- G_{31}, Y_7, Y_{12}

G_{160} snow surface temperature -- G_2, G_{118}, G_{121}, G_{170}

G_{161} freezing of free water in snowpack -- $F(98,2)$, G_{10}

G_{168} net heat transfer from sky to canopy due to longwave radiation -- G_{169}

G_{169} heat input to canopy due to long- and shortwave radiation -- G_6, G_{20}

G_{170} heat input to snowpack due to convection -- G_{127}

6.2. *Descriptions of Intermediate Functions*

Illustrations for some of the functions appear at the end of this section.

G_1 = one-sided needle surface area index (dim.)

$$G_1 = B_7 G_{61}$$

G_{61} = total foliage carbon (t/ha)
B_7 = ratio of one-sided needle surface area to needle carbon mass (ha/t)

Comment: The estimate of the ratio of one-sided leaf area to biomass is from Reed (1971) for Douglas-fir. We are assuming this holds for minor species as well.

G_2 = heat input to snowpack due to condensation (ly/day)

$$G_2 = \max \{0,\ 80 B_{22}[S_1(Z_5) - S_1(G_{160})]\}$$

G_{160} = snow surface temperature (deg)
Z_5 = average 24-hr dew point temperature (deg)
$S_1(Z_5)$ = vapor pressure of air (mbar)
$S_1(G_{160})$ = saturation vapor pressure of air at snow surface computed using Teten's equation (mbar)
B_{22} = ratio of snowmelt condensation due to vapor pressure deficit ($g \cdot cm^{-2} \cdot day^{-1} \cdot mbar^{-1}$)

Comment: The factor 80 is the heat of fusion of water (cal/g). This relationship between condensation and dew point temperature is based on a four-year study at Willamette Basin Snow Laboratory (U.S. Army Corps of Engineers 1956). We are ignoring snow sublimation but it could be important in places where the sun shines in the winter. The term $S_1(Z_5)$ - $S_1(G_{160})$ is a measure of the vapor pressure gradient at the snowpack surface.

G_3 = rain input to foliar surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_3 = G_{23} G_{13} G_{54}$$

G_{13} = fraction of rain incident to canopy which strikes foliage (dim.)
G_{23} = percent cover by canopy (dim.)
G_{54} = precipitation as rain ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

G_4 = rain input to epiphyte and bark surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_4 = G_{23}(1 - G_{13})G_{54}$$

G_{13} = fraction of rain incident to canopy which strikes foliage (dim.)
G_{23} = percent cover by canopy (dim.)
G_{54} = precipitation as rain ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

G_5 = drip from foliar surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_5 = \max \{0,\ T_1(X_1 - G_{16}G_{57}) + (G_3 - G_{57}G_6)[1 - (T_1/B_{170})]\}$$

$$T_1 = 1 - \exp(-B_{170})$$

X_1 = water storage on foliage (m^3/ha)
G_3 = rain input to foliar surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_6 = potential evaporation from canopy ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{16} = water retention capacity of canopy (m^3/ha)
G_{57} = fraction of water retention capacity of canopy due to foliage (dim.)
B_{170} = rate constant for water drainage from canopy (day^{-1})

Comment: This expression is based on the differential equation

$$(dX_1/dt) = G_3 - G_{57}G_6 - B_{170}(X_1 - G_{16}G_{57})$$

which assumes rain input at constant rate G_3, evaporation at constant rate $G_{57}G_6$, and drainage at a rate depending upon the amount of water X_1 in excess of storage capacity $G_{16}G_{57}$. It is a linear differential equation and may be solved analytically. The rate of water transfer out of X_1 is given by

$$G_5 = B_{170}\int_0^1 X_1\, dt - G_{16}G_{57}$$

This approach was necessary since storage capacity of the foliage $G_{16}G_{57}$ is often smaller than the daily rain input. A similar approach was used for water storage on epiphyte and bark surfaces, litter moisture, and soil moisture (see G_{56}, G_{15}, and G_{12}, respectively).

G_6 = potential evaporation from canopy ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_6 = \max \left\{ \frac{B_{159}[G_{17}G_{169}B_{164}Z_4 + (G_{99}/G_{100})]}{B_{157}(G_{17} + B_{158})},\ 0 \right\}$$

G_{17} = rate of change of saturation vapor pressure with temperature (mbar/deg)
G_{99} = vapor pressure deficit (mbar $joules \cdot m^{-3} \cdot deg^{-1}$)
G_{100} = aerodynamic resistance (sec/m)
G_{169} = heat input to canopy due to long- and shortwave radiation (ly/day)
Z_4 = day length (dim.)
B_{157} = latent heat of vaporization of water (joules/kg)
B_{158} = psychrometric constant (mbar/deg)
B_{159} = factor to convert $kg \cdot m^{-2} \cdot sec^{-1}$ to $m^3 \cdot ha^{-1} \cdot day^{-1}$ ($sec \cdot m^5 \cdot day^{-1} \cdot kg^{-1} \cdot ha^{-1}$)
B_{164} = factor to convert net radiation from ly/day to $joules \cdot m^{-2} \cdot sec^{-1}$ ($joule \cdot day \cdot m^{-2} \cdot sec^{-1} \cdot ly^{-1}$)

Comment: Function is based on Penman's (1963) equation for evaporation as function of temperature, dew point temperature, incoming short- and longwave radiation, and wind speed. Note that 1 m^3 of water weighs 1000 kg.

G_7 = evaporation from foliage ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_7 = \begin{cases} G_6 G_{57} & \text{if } G_5 \leq X_1 + G_3 - G_6 G_{57} \\ X_1 + G_3 - G_5 & \text{if } G_5 > X_1 + G_3 - G_6 G_{57} \end{cases}$$

X_1 = water storage on foliage (m^3/ha)
G_3 = rain input to foliar surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_5 = drip from foliar surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_6 = potential evaporation from canopy ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{57} = fraction of water retention capacity of canopy due to foliage (dim.)

Comment: If drip G_5 is larger than the amount of water stored on the foliage less potential evaporation then we reduce evaporation from the foliage so that both flows combined reduce the pool size to zero. Note that G_{57}, the fraction of retention capacity due to foliage, is used here to give the fraction of total evaporation from the canopy which is met from storage on foliar surfaces.

G_8 = evaporation from epiphyte and bark surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_8 = \begin{cases} G_6(1 - G_{57}) & \text{if } G_{56} \leq X_8 + G_4 - G_6(1 - G_{57}) \\ X_8 + G_4 - G_{56} & \text{if } G_{56} > X_8 + G_4 - G_6(1 - G_{57}) \end{cases}$$

X_8 = water storage on epiphyte and bark surfaces (m^3/ha)
G_4 = rain input to epiphyte and bark surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_6 = potential evaporation from canopy ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{56} = drip from epiphyte and bark surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{57} = fraction of water retention capacity of canopy due to foliage (dim.)

Comment: See explanation of G_7 which is analogous.

G_9 = rainfall passing directly to snowpack ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_9 = (1 - G_{23}) G_{54}$$

G_{23} = percent cover by canopy (dim.)
G_{54} = precipitation as rain ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

G_{10}= water transfer from snowpack to litter surface ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{10} = \begin{cases} \max(T_1, 0) & \text{if } G_{60} \neq G_{129} \\ G_{130} + \max(T_1, 0) & \text{if } G_{60} = G_{129} \end{cases}$$

$$T_1 = G_{129} + X_{98} + G_{74} + G_{75} + G_{76} - G_{161} - G_{130}$$

X_{98} = free water in snowpack (m^3/ha)
G_{60} = snowpack ice plus current day's snowfall (m^3/ha)

G_{74} = rainfall passing directly to free water in snowpack ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{75} = drip from foliar surfaces to free water in snowpack ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{76} = drip from epiphyte and bark surfaces to free water in snowpack ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{129} = transfer from ice to free water in snowpack ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{130} = free-water-holding capacity of snow (m^3/ha)
G_{161} = freezing of free water in snowpack ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

Comment: Here T_1 gives new value for free water in snow after melting, freezing, and rain input are accounted for. If this does not exceed holding capacity G_{130}, then water does not drain from the snowpack. If the holding capacity is less than T_1 then the excess free water drains to the litter surface. The second case ensures that, on a day on which all snow (existing plus incoming) melts, no free water remains in the snowpack.

G_{11} = water entering litter ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{11} = \begin{cases} G_{134} + G_{10} & \text{if } G_{60} \leq 0.001 \\ G_{10} & \text{if } G_{60} > 0.001 \end{cases}$$

G_{10} = transfer from snowpack to litter surface ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{60}= snowpack ice plus current day's snowfall (m^3/ha; see 3.2)
G_{134} = total water input to snowpack or litter layer ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

Comment: When snowpack is present only drainage from the pack (G_{10}) enters the litter. When the pack is absent, drip plus direct rainfall enter directly into the litter. The inclusion of G_{10} in this last case pertains to the day immediately after the last snow melts, as discussed under G_{10}. We check for $G_{60} > 0.001$ rather than 0.0 to avoid problems with roundoff errors.

G_{12} = water transfer from rooting zone to subsoil ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{12} = \max\ (0,\ T_1 [(G_{15} - G_{20}) (\frac{1}{T_1} - \frac{1}{B_9}) + X_3 - B_{13}]$$

$$T_1 = 1 - \exp\ (-B_9)$$

X_3 = soil rooting zone water (m^3/ha)
G_{15} = water transfer from litter to soil rooting zone (m^3/ha)
G_{20} = transpiration rate ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
B_9 = rate constant for soil water drainage (day^{-1})
B_{13} = water retention capacity of soil (m^3/ha)

Comment: This expression is based on a differential equation for water flow through the soil in which water flows out at a rate depending upon soil moisture X_3.

$$\frac{dX_3}{dt} = G_{15} - B_9 (X_3 - B_{13}) - G_{20}$$

See G_5 and G_{15}, which are analogous.

G_{13} = fraction of rain incident to canopy which strikes foliage (dim.)

$$G_{13} = \frac{G_{61}}{G_{61} + B_{172}X_{13}}$$

X_{13} = stem-plus-branch carbon (t/ha)
G_{61} = total foliage carbon (t/ha)
B_{172} = ratio of intercepting area to carbon mass for stems plus branches divided by same ratio for foliage (dim.)

Comment: We assume a constant ratio of intercepting area due to bark and epiphytes to stem-plus-branch carbon mass. We express this intercepting area ($B_{172}X_{13}$) in terms of an equivalent amount of foliage and add it to old plus new foliage when computing total intercepting area.

G_{14} = potential evaporation from litter ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{14} = \max \left\langle 0, \frac{B_{163}\{S_1(X_{25}) - S_1[Z_5 - (Z_3 - X_{25})]\}B_{155}B_{154}B_{159}}{B_{157}B_{158}} \right\rangle$$

X_{25} = litter temperature (deg)
$S_1(X_{25})$ = vapor pressure at litter temperature (mbar)
$S_1[Z_5 - (Z_3 - X_{25})]$ = vapor pressure at litter dew point temperature (mbar)
Z_3 = air temperature (deg)
B_{154} = density of saturated air (kg/m^3)
B_{155} = specific heat of saturated air ($joules \cdot kg^{-1} \cdot deg^{-1}$)
B_{157} = latent heat of vaporization of water (joules/kg)
B_{158} = psychrometric constant (mbar/deg)
B_{159} = factor to convert $kg \cdot m^{-2} \cdot sec^{-1}$ to $m^3 \cdot ha^{-1} \cdot day^{-1}$ ($sec \cdot m^5 \cdot deg^{-1} \cdot kg^{-1} \cdot ha^{-1}$)
B_{163} = aerodynamic conductance at litter surface (m/sec)

Comment: This is the Penman equation for evaporation (Penman 1963) except that heat input to litter due to radiation was assumed to be negligible. To get litter dew point temperature we reduce air dew point temperature (Z_5) by the difference between air temperature and litter temperature.

G_{15} = water transfer from litter to soil rooting zone ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{15} = \begin{cases} T_1(T_2 + X_7 - B_{20}G_{55}) & X_7 > B_{20}G_{55} \\ 0 & X_7 \le B_{20}G_{55} \end{cases}$$

$$T_1 = 1 - \exp(-B_{165})$$

$$T_2 = (G_{11} - G_{14})(1/T_1 - 1/B_{165})$$

X_7 = litter water (m^3/ha)
G_{11} = water entering litter ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{14} = potential evaporation from litter ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{55} = water-holding capacity of litter (m^3/ha)
B_{20} = fraction of litter water-holding capacity below which drainage ceases (dim.)
B_{165} = rate constant for drainage from litter (day^{-1})

Comment: When X_7 exceeds the retention capacity $B_{20}G_{55}$, and there are large inputs of water, outflow may be large compared with pool size and variation in pool size throughout the day must be considered. We set up a differential equation in which we assume water inflow (G_{11}) and evaporation (G_{14}) are constant but that drainage occurs at a rate proportional to water amount in excess of retention capacity

$$\frac{dX_7}{dt} = G_{11} - G_{14} - B_{165}(X_7 - B_{20}G_{55}) \qquad X_7 > B_{20}G_{55}$$

Solving this expression analytically for X_7 after one day, we get an expression which we can solve for G_{15}. Notice that if $X_7 \leq B_{20}G_{55}$ we assume $G_{15} = 0$. It can happen also that with large water inflow G_{11}, X_7 may be greater than G_{55} and some water input will flow out the same day. We neglect this possibility and let the water drain the next day.

G_{16} = water retention capacity of canopy (m^3/ha)

$$G_{16} = B_3(G_{61} + B_{173}X_{13})$$

X_{13} = stem-plus-branch carbon (t/ha)
G_{61} = total foliage carbon (t/ha)
B_3 = ratio of water retention capacity to foliar carbon mass (m^3/t)
B_{173} = ratio of storage capacity to carbon mass for stems plus branches divided by same ratio for foliage (dim.)

Comment: Storage capacity is assumed to increase with increasing canopy biomass. The storage capacity due to stems plus branches (X_{13}) is actually due to bark and epiphyte surfaces. The factor B_{173} extrapolates stem-plus-branch carbon to bark and epiphyte surface area (which are not directly available in the model) and then converts this surface area to storage capacity. Storage capacity is expressed in terms of an equivalent amount of foliage (see also discussion of intercepting area -- G_{13})

G_{17} = rate of change of saturation vapor pressure with temperature (mbar/deg)

$$G_{17} = \frac{B_{18}B_{72}G_{21}}{(Z_3 + B_{18})^2}$$

G_{21} = saturation vapor pressure at air temperature (mbar)
Z_3 = average 24-hr air temperature (deg)
B_{18} = coefficient in Teten's equation (deg)
B_{72} = coefficient in Teten's equation (dim.)

Comment: This equation was obtained by differentiating with respect to temperature the curve relating saturation vapor pressure to temperature (Murray 1967).

G_{18} = outflow from groundwater ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{18} = \max \begin{cases} 0 \\ X_5 - B_{16} \end{cases}$$

X_5 = groundwater storage (m^3/ha)
B_{16} = retention capacity of groundwater zone (m^3/ha)

Comment: Groundwater is assumed constant in CONIFER.

G_{19} = water transfer from subsoil to groundwater ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{19} = \max \{0, T_1 [G_{12} (\frac{1}{T_1} - \frac{1}{B_{10}}) + X_4 - B_{14})]\}$$

$$T_1 = 1 - \exp(-B_{10})$$

X_4 = subsoil water (m^3/ha)
G_{12} = water transfer from soil rooting zone to subsoil ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
B_{10} = rate constant for subsoil water drainage (day^{-1})
B_{14} = water retention capacity of subsoil (m^3/ha)

Comment: This is based on the differential equation:

$$\frac{dX_4}{dt} = G_{12} - B_{10}(X_4 - B_{14})$$

See also G_5, G_{15}, and G_{12}.

G_{20} = transpiration rate ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{20} = \begin{cases} \dfrac{B_{159}[G_{17}G_{169}B_{164}Z_4 + G_{99}/G_{100}]}{B_{157}[G_{17} + B_{158}(1 + G_{101}/2G_1G_{100})]} & \text{if } X_1 + G_3 - G_5 - G_7 < B_{171} \\ 0 & \text{if } X_1 + G_3 - G_5 - G_7 \geq B_{171} \text{ or } X_3 < B_5 \end{cases}$$

X_1 = water storage on foliage (m^3/ha)
X_3 = soil rooting zone water (m^3/ha)
G_1 = one-sided needle surface area index (dim.)
G_3 = rain input to foliar surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_5 = drip from foliar surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_7 = evaporation from foliar surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{17} = rate of change of saturation vapor pressure with temperature (mbar/deg)
G_{99} = vapor pressure deficit (mbar joules$\cdot m^{-3} \cdot deg^{-1}$)
G_{100} = aerodynamic resistance (sec/m)
G_{101} = canopy resistance (sec/m)
G_{169} = heat input to canopy due to long- and shortwave radiation (ly/day)
Z_4 = day length (dim.)
B_5 = soil moisture value below which transpiration ceases (m^3/ha)
B_{157} = latent heat of vaporization of water (joules/kg)
B_{158} = psychrometric constant (mbar/deg)
B_{159} = factor to convert $kg \cdot m^{-2} \cdot sec^{-1}$ to $m^3 \cdot ha^{-1} \cdot day^{-1}$ ($sec \cdot m^5 \cdot deg^{-1} \cdot kg^{-1} \cdot ha^{-1}$)
B_{164} = factor to convert net radiation from ly/day to $joule \cdot m^{-2} \cdot sec^{-1}$ ($joule \cdot day \cdot m^{-2} \cdot sec^{-1} \cdot ly^{-1}$)
B_{171} = water storage on foliage above which there is no transpiration (m^3/ha)

Comment: This is Penman's equation for evaporation as modified for transpiration to include leaf resistance (Montieth 1965). The 2 in the denominator of G_{20} converts one-sided needle surface area index (NSAI) G_1 to two-sided NSAI. Division by two-sided NSAI converts G_{101} from a unit leaf area to a unit ground area basis.

G_{21} = saturation vapor pressure at air temperature (mbar)

$$G_{21} = S_1(Z_3)$$

Z_3 = average 24-hr air temperature (deg)
S_1 = saturation vapor pressure as function of temperature

G_{22} = evaporation from litter ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{22} = \begin{cases} G_{14} & \text{if } X_7 > B_{11}G_{55} \\ \max\{0, (G_{11} + X_7 - B_{12}G_{55})[1 - \exp(-G_{14}/T_1)]\} & \text{if } B_{11}G_{55} \geq X_7 \geq B_{12}G_{55} \\ 0 & \text{if } X_7 < B_{12}G_{55} \end{cases}$$

$$T_1 = (B_{11} - B_{12})G_{55}$$

X_7 = litter water (m^3/ha)
G_{11} = water entering litter ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{14} = potential evaporation from litter ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{55} = water-holding capacity of litter (m^3/ha)
B_{11} = fraction of litter water-holding capacity below which there is resistance to evaporation (dim.)
B_{12} = fraction of litter water-holding capacity below which evaporation ceases (dim.)

Comment: The evaporation function G_{22}, as well as the flow rate of water out of litter G_{15}, are based on solutions to linear differential equations integrated over a day. This approach was used because of rapid turnover of X_7. The differential equation becomes important within the litter moisture range $B_{11}G_{55} \geq X_7 \geq B_{12}G_{55}$. Here

$$\frac{dX_7}{dt} = G_{11} - \frac{G_{14}(X_7 - B_{12}G_{55})}{(B_{11} - B_{12})G_{55}}$$

Note that the evaporation rate is reduced from potential evaporation in proportion to the litter water pool X_7.

G_{23} = percent cover canopy (dim.)

$$G_{23} = 1 - \exp[-B_{174}(G_{61} + B_{172}X_{13})]$$

X_{13} = stem-plus-branch carbon (t/ha)
G_{61} = total foliage carbon
B_{172} = ratio of intercepting area to carbon mass for stems plus branches divided by same ratio for foliage (dim.)
B_{174} = coefficient for effect of foliar carbon mass on intercepting area (ha/t)

Comment: Here G_{23} is also used for percent cover by overstory alone in the equation for shortwave radiation attenuation by the canopy (G_{91}).

G_{24} = net new foliage photosynthesis ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{24} = \frac{-B_{32}B_{33}G_{110}X_{10}T_1G_{102}}{B_{35}G_{49}G_{61}}$$

T_1 = logarithmic part of photosynthesis expression (dim.)
X_{10} = new foliage carbon (t/ha)
G_{49} = average weekly stomatal resistance of new foliage (sec/cm)
G_{61} = total foliage carbon (t/ha)
G_{102} = effect of temperature on photosynthesis ($deg^{-B_{177}}$)
G_{110} = average weekly day length (dim.)
B_{32} = ratio of net new foliage photosynthesis based on carbon budget to amount extrapolated from cuvette experiments (dim.)
B_{33} = rate constant for new foliage photosynthesis ($sec \cdot cm^{-1} \cdot deg^{-B_{177}} \cdot wk^{-1}$)
B_{35} = coefficient for attenuation of shortwave radiation by foliage (ha/t)

Comment: New leaf photosynthesis is directly proportional to fraction of total foliage comprising new leaves. The minus sign occurs because T_1 is negative.

T_1 = logarithmic part of photosynthesis expression (dim.)

$$T_1 = \ln \left[\frac{B_{34} + G_{109} \exp(-B_{35}G_{61})}{B_{34} + G_{109}} \right]$$

G_{61} = total foliage carbon (t/ha)
G_{109} = average weekly photosynthetically active radiation (ly/min)
B_{34} = light intensity at which new foliage photosynthesis is one-half maximum rate (ly/min)
B_{35} = coefficient for attenuation of shortwave radiation by foliage (ha/t)

Comment: The shortwave radiation extinction coefficient assumes 5% light penetration through the canopy for average leaf area. The half maximum rate light intensity (B_{34}) was obtained from cuvette data (Salo 1974). The expression in the numerator is smaller than the denominator making T_1 negative.

G_{25} = new foliage nighttime respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{25} = B_{26}(1 - G_{110})X_{10} \exp (B_{145}G_{108})$$

X_{10} = new foliage carbon (t/ha)
G_{108} = average weekly nighttime air temperature (deg
G_{110} = average weekly day length (dim.)
B_{26} = foliar respiration rate constant (wk^{-1})
B_{145} = coefficient for temperature effect on foliar respiration (deg^{-1})

G_{26} = transfer of carbon to new foliage from new foliage CH_2O pool ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{26} = \begin{cases} T_1 & \text{if } 0 < T_1 < G_{46} \\ 0 & \text{if } T_1 \leq 0 \\ G_{46} & \text{if } T_1 \geq G_{46} \end{cases}$$

T_1 = surplus carbon available for new foliage growth

$$T_1 = G_{47} + G_{45}$$

G_{45} = portion of growth CH_2O pool available for foliar respiration and growth ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{46} = new foliage growth demand ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{47} = surplus or deficit of new foliage photosynthate after new foliage respiration is satisfied ($t \cdot ha^{-1} \cdot wk^{-1}$)

Comment: If there is no surplus ($T_1 \leq 0$) there is no new foliage growth. If the surplus is less than the growth demand, the surplus is transferred to new foliage. If the surplus is greater than growth demand only the demand (G_{46}) goes to new foliage--the rest goes into the growth CH_2O pool.

The new foliage CH_2O pool (X_{64}) acts as a clearinghouse through which flows between the atmosphere, new foliage, and the growth CH_2O pool (X_{12}) are channeled. G_{26}, G_{27}, G_{28}, and G_{32} all represent flows into or out of X_{64}.

G_{27} = transfer of carbon from new foliage to new foliage CH_2O pool ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{27} = \begin{cases} -(G_{47} + G_{45}) & \text{if } G_{47} + G_{45} < 0 \\ 0 & \text{otherwise} \end{cases}$$

G_{45} = portion of growth CH_2O pool available for foliar respiration and growth ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{47} = surplus or deficit of new foliage photosynthate after new foliage respiration is satisfied ($t \cdot ha^{-1} \cdot wk^{-1}$)

Comment: In this case G_{47} is negative and the new foliage respiration demand cannot be met from new foliage photosynthesis or by transfer from the growth CH_2O pool. New foliage tissue is utilized for respiration.

G_{28} = transfer of surplus carbon from new foliage CH_2O pool to growth CH_2O pool ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{28} = \begin{cases} 0 & \text{if } T_1 < 0 \\ G_{47} & \text{if } G_{47} < 0 \text{ and } T_1 \geq 0 \\ \max(0,\ G_{47} - G_{46}) & \text{if } G_{47} \geq 0 \end{cases}$$

T_1 = surplus carbon available for new foliage growth

$$T_1 = G_{47} + G_{45}$$

G_{45} = portion of growth CH_2O pool available for foliar respiration and growth ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{46} = new foliage growth demand ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{47} = surplus or deficit of new leaf photosynthate after new foliage respiration is satisfied ($t \cdot ha^{-1} \cdot wk^{-1}$)

Comment: If respiration cannot be met by new foliage photosynthate ($G_{47} < 0$) but can be met from growth CH_2O pool ($T_1 \geq 0$), the deficit (G_{47}) is transferred from growth CH_2O pool to new foliage CH_2O pool. If it cannot be met ($T_1 < 0$), then G_{28} is zero. If there is a surplus after respiration, there will be transfer of $G_{47} - G_{46}$ to growth CH_2O pool.

G_{29} = net old foliage photosynthesis ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{29} = \frac{B_{32} B_{41} G_{110} X_{11} T_1 G_{102}}{B_{35} G_{58} G_{61}}$$

T_1 = logarithmic part of photosynthesis expression (dim.)
X_{11} = old foliage carbon (t/ha)
G_{58} = average weekly stomatal resistance of old foliage (sec/cm)
G_{61} = total foliage carbon (t/ha)
G_{102} = temperature effect on photosynthesis ($deg^{-B_{177}}$)
G_{110} = average weekly day length (dim.)
B_{32} = ratio of net new foliage photosynthesis based on carbon budget to amount extrapolated from cuvette experiments (dim.)
B_{35} = coefficient for attenuation of shortwave radiation by foliage (ha/t)
B_{41} = rate constant for old foliage photosynthesis ($sec \cdot cm^{-1} \cdot deg^{-B_{177}} \cdot wk^{-1}$)

Comment: See curves for new foliage photosynthesis. Here T_1 is negative and is analogous to T_1 in the expression for new foliage photosynthesis

T_1 = logarithmic part of photosynthesis expression (dim.)

$$T_1 = \ln\left(\frac{B_{42} + G_{109}\exp(-B_{35}G_{61})}{B_{42} + G_{109}}\right)$$

G_{61} = total foliage carbon (t/ha)
G_{109} = average weekly photosynthetically active radiation (ly/min)
B_{35} = coefficient for attenuation of shortwave radiation by foliage (ha/t)
B_{42} = shortwave radiation value at which old foliage photosynthesis is one-half maximum (ly/min)

Comment: T_1 is negative and is analogous to T_1 in new foliage photosynthesis G_{24}.

G_{30} = old foliage nighttime respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{30} = \frac{B_{27}B_{26}(1 - G_{110})X_{11}X_{12}\exp(B_{145}G_{108})}{B_{44} + X_{12}}$$

X_{11} = old foliage carbon (t/ha)
X_{12} = carbon in growth CH_2O pool (t/ha)
G_{108} = average weekly nighttime air temperature (deg)
G_{110} = average weekly day length (dim.)
B_{26} = foliar respiration rate constant (wk^{-1})
B_{27} = ratio of old foliage to new foliage respiration (dim.)
B_{44} = value of growth pool at which old foliage respiration is one-half maximum (t/ha)
B_{145} = coefficient for temperature effect on foliar respiration (deg^{-1})

Comment: Differs from new foliage respiration in that G_{30} is affected directly by the size of the growth CH_2O pool.

G_{31} = total respiratory loss from growth CH_2O pool ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{31} = G_{30} + G_{138} + G_{139} + G_{140}$$

G_{30} = old foliage nighttime respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{138} = stem plus branch respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{139} = large root respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{140} = fine root respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

G_{32} = transfer of carbon from growth CH_2O pool to new foliage CH_2O pool to meet foliar respiration and growth demands ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{32} = \begin{cases} G_{45} & \text{if } T_1 \le G_{46} \quad G_{47} \le 0 \\ G_{46} & \text{if } T_1 > G_{46} \quad G_{47} \le 0 \\ 0 & \text{if } T_2 \le 0 \quad G_{47} > 0 \\ T_2 & \text{if } T_2 \le G_{45} \quad G_{47} > 0 \\ G_{45} & \text{if } T_2 > G_{45} \quad G_{47} > 0 \end{cases}$$

T_1 = surplus carbon available for new foliage growth

$$T_1 = G_{47} + G_{45}$$

T_2 = portion of new foliage growth demand not satisfied by new foliage photosynthesis

$$T_2 = G_{46} - G_{47}$$

G_{45} = portion of growth CH_2O pool available for foliar respiration and growth $(t \cdot ha^{-1} \cdot wk^{-1})$
G_{46} = new foliage growth demand $(t \cdot ha^{-1} \cdot wk^{-1})$
G_{47} = surplus or deficit of new foliage photosynthate after new foliage respiration is satisfied $(t \cdot ha^{-1} \cdot wk^{-1})$

Comment: Cases I-II: New foliage respiration exceeds or equals new foliage photosynthesis ($G_{47} \leq 0$):

I. Available carbon is insufficient to meet entire growth demand. All available carbon is transferred.
II. Available carbon exceeds demand. Only demand is transferred.

Cases III-V: New foliage respiration is less than new foliage photosynthesis ($G_{47} > 0$):

III. Entire growth demand is met from new foliage photosynthesis. No carbon is transferred.
IV. Foliage growth demand which is not met by new foliage photosynthesis is less than what is available from growth pool. Only enough is transferred to meet demand.
V. Demand exceeds what is available. Only available is transferred.

G_{33} = bud growth $(t \cdot ha^{-1} \cdot wk^{-1})$

$$G_{33} = \begin{cases} B_{31}G_{39} & \text{if } G_{106} \neq 0 \\ 0 & \text{otherwise} \end{cases}$$

G_{39} = temperature effect on growth processes (dim.)
G_{106} = phenology of tree growth (dim.)
B_{31} = bud growth rate constant (wk^{-1})
t_w = time (wk modulo 52)

Comment: No dependence on size of growth pool is included because we feel that bud growth should have priority over all other growth processes and respiration.

G_{34} = maturation of new foliage $(t \cdot ha^{-1} \cdot wk^{-1})$

$$G_{34} = \begin{cases} X_{10} + G_{26} - G_{27} - G_{38} & \text{if } t_w = M_4 \\ 0 & \text{otherwise} \end{cases}$$

X_{10} = new foliage carbon (t/ha)
G_{26} = transfer of carbon to new foliage from new foliage CH_2O pool ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{27} = transfer of carbon from new foliage to new foliage CH_2O pool ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{38} = new foliage consumption by insects ($t \cdot ha^{-1} \cdot wk^{-1}$)
M_4 = week on which new foliage becomes old foliage
t_w = time (wk modulo 52)

Comment: All new foliage is assumed to become old foliage at week 40. Growth minus losses for that week are also accounted for.

G_{35} = carbon transfer to stems plus branches ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{35} = \begin{cases} \dfrac{B_{45}G_{39}X_{12}}{B_{46} + X_{12}} & \text{if } G_{106} > 0 \\ 0 & \text{if } G_{106} = 0 \end{cases}$$

X_{12} = carbon in growth CH_2O pool (t/ha)
G_{39} = temperature effect on growth processes (dim.)
G_{106} = phenology of tree growth (dim.)
B_{45} = maximum rate of carbon transfer from growth CH_2O pool to stems plus branches ($t \cdot ha^{-1} \cdot wk^{-1}$)
B_{46} = value of growth pool at which respiration of and transfer to stems plus branches is one-half maximum (t/ha)

Comment: The coefficient called "maximum" rate is actually maximum rate at the optimum temperature.

G_{36} = carbon transfer to large roots

$$G_{36} = \frac{B_{47}G_{53}X_{12}}{B_{48} + X_{12}}$$

X_{12} = carbon in growth CH_2O pool (t/ha)
G_{53} = effect of soil temperature on soil processes (dim.)
B_{47} = maximum rate of carbon transfer from growth CH_2O pool to large roots ($t \cdot ha^{-1} \cdot wk^{-1}$)
B_{48} = growth pool value at which respiration of and transfer to large roots is one-half maximum (t/ha)

Comment: See G_{35}.

G_{37} = carbon transfer to fine roots ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{37} = \frac{B_{49}G_{53}X_{12}}{B_{50} + X_{12}}$$

X_{12} = carbon in growth CH_2O pool (t/ha)
G_{53} = effect of soil temperature on soil processes (dim.)

B_{49} = maximum rate of carbon transfer from growth CH_2O pool to fine roots ($t \cdot ha^{-1} \cdot wk^{-1}$)
B_{50} = value of growth pool at which respiration of and transfer to fine fine roots is one-half maximum (t/ha)

Comment: The small value of B_{50} implies that G_{37} is usually unaffected by changes in X_{12}. It gives transfer to fine roots precedence over other transfers when growth CH_2O pool is low, since all other transfers to live plant parts are also regulated by CH_2O pool. See G_{35}.

G_{38} = insect consumption of new foliage ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{38} = B_{56} X_{10} G_{39}$$

X_{10} = new foliage carbon (t/ha)
G_{39} = temperature effect on growth processes (dim.)
B_{56} = rate constant for new foliage consumption (wk^{-1})

Comment: Amount of new foliage consumed by insects. This is a dummy function (depending on temperature function [G_{39}] and new foliage carbon only) designed solely to cause leaves to disappear in a reasonable seasonal pattern. There is no dependence on insect biomass.

G_{39} = temperature effect on growth processes (dim.)

$$G_{39} = B_{36} S_2 (G_{48}, 0, B_{76}, B_{77})$$

G_{48} = average weekly 24-hour air temperature (deg)
S_2 = beta function
B_{36} = factor such that G_{39} averages 1.0 over the first year ($deg^{-B_{77}}$)
B_{76} = temperature above which growth processes cease (deg)
B_{77} = coefficient determining shape of G_{39} curve (dim.)

Comment: G_{39} is also used to control timing of insect consumption.

G_{40} = leaf fall rate ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{40} = (T_1 + B_{182}) X_{11} + 0.5 G_{93}$$

$$T_1 = \begin{cases} B_{43} S_2 (t_w, M_5 - 52, M_5, B_{91}) & \text{if } t_w \leq M_5 \\ B_{43} S_2 (t_w, M_5, M_5 + 52, B_{91}) & \text{if } t_w > M_5 \end{cases}$$

X_{11} = old foliage carbon (t/ha)
G_{93} = acute old foliage defoliation ($t \cdot ha^{-1} \cdot wk^{-1}$)
S_2 = beta function
B_{43} = factor so that G_{40} integrated over one year is 1.0 [$wk^{-(B_{91} + 1)}$]
B_{91} = coefficient for shape of leaf fall curve (dim.)
B_{182} = minimum leaf fall rate constant (wk^{-1})
M_5 = week on which leaf fall is minimum
t_w = time (wk modulo 52)

Comment: Function describes pattern of leaf fall through the year; B_{182} causes a constant leaf fall rate during the year to which a time-varying leaf fall rate (T_1) is added. The time-varying part (T_1) is constructed so that the area under the curve is 1.0 (all the leaves that are to fall in one year thus do so). The pattern repeats each year. Each year the start time is -17 (1 October of the previous year), and the finish time is 35 (1 October of the current year). The 0.5 in the defoliation part is because half of removed foliage goes to foliage litter (X_{19}) and half to fine litter (X_{20}) as frass.

G_{41} = weekly average litter temperature (deg)

$$G_{41} = X_{25}$$

X_{25} = litter temperature (deg)

Comment: In this model litter temperature is calculated weekly. In other versions this has been changed to a daily calculation and G_{41} is used to calculate average weekly temperature. We set $G_{41} = X_{25}$ simply for consistency between the various versions.

G_{42} = plant moisture stress (PMS; atm)

$$G_{42} = \begin{cases} B_{84} - B_{85}(X_3 - B_5) & \text{if } B_5 < X_3 \leq B_{82} \text{ and } Z_3 \geq B_{79} \\ B_{78} & \text{if } X_3 > B_{82} \text{ and } Z_3 \geq B_{79} \\ B_{84} & \text{if } X_3 \leq B_5 \text{ or if } Z_3 < B_{79} \end{cases}$$

X_3 = soil rooting zone water (m^3/ha)
Z_3 = average 24-hr air temperature (deg)
B_5 = soil moisture value below which transpiration ceases (m^3/ha)
B_{78} = minimum PMS (atm)
B_{79} = air temperature above which PMS is unaffected by temperature (deg)
B_{82} = soil moisture value above which PMS does not change (m^3/ha)
B_{84} = maximum PMS (atm)
B_{85} = rate of increase of PMS with increasing soil moisture content ($atm \cdot ha^{-1} \cdot m^{-3}$)

Comment: As soil moisture drops below 66% holding capacity, PMS increases as a linear function of soil moisture (Running et al. 1975). Here PMS refers to weekly average predawn plant moisture stress.

G_{43} = new foliage stomatal resistance (sec/cm)

$$G_{43} = \begin{cases} B_{88} \exp (B_{89} G_{42}) & \text{if } G_{42} \leq B_{87} \\ B_{86} & \text{if } G_{42} > B_{87} \end{cases}$$

G_{42} = plant moisture stress (atm)
B_{86} = maximum new foliage stomatal resistance (sec/cm)
B_{87} = plant moisture stress above which there is no increase in new foliage resistance (atm)
B_{88} = new foliage stomatal resistance when PMS is 0.0 (sec/cm)
B_{89} = coefficient for effect of PMS on new foliage stomatal resistance (atm^{-1})

Comment: Based on model by Running et al. (1975). Resistance includes both stomatal and mesophyll resistances.

G_{44} = change in last year's bud carbon (t/ha)

$$G_{44} = \begin{cases} -X_{38} & \text{if } G_{106} = 0 \\ X_{16}(1 - B_{167}) & \text{if } t_w = M_1 \\ -\min\left[\frac{G_{38}}{B_{37}} + S_6(B_{166}, B_{169}, B_{167}X_{38}), X_{38}\right] & \text{otherwise} \end{cases}$$

X_{16} = bud carbon--current year (t/ha)
X_{38} = bud carbon--previous year (t/ha)
G_{38} = new foliage consumption by insects ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{106} = phenology of tree growth (dim.)
S_6 = delta function
B_{37} = ratio of leaf carbon mass to bud carbon (dim.)
B_{166} = first day on which new foliage is to be removed
B_{167} = fraction by which foliage to be reduced during acute defoliation (dim.)
B_{169} = second day on which new foliage is to be removed
M_1 = week on which budbreak occurs
t_w = time (wk modulo 52)

Comment: Here X_{38} keeps track of limit to growth of foliage in terms of buds decreased by any consumption by insects or other defoliation. On week M_1, actual bud biomass (X_{16}) becomes previous year bud biomass (X_{38}). During dormant season (while $G_{106} = 0$), X_{38} remains empty. Note that both X_{38} and G_{44} give potential foliage in terms of bud weight. Here B_{166}, B_{167}, and B_{169} are parameters used only for defoliation perturbations; $S_6 = B_{167}X_{38}$ when $t_d = B_{166}$ or B_{169}.

G_{45} = portion of growth CH_2O pool available for foliar respiration and growth ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{45} = \frac{B_{39}X_{12}}{B_{40} + X_{12}}$$

X_{12} = carbon in growth CH_2O pool (t/ha)
B_{39} = maximum rate of carbon transfer from growth CH_2O pool to new foliage CH_2O pool ($t \cdot ha^{-1} \cdot wk^{-1}$)
B_{40} = value of growth CH_2O pool at which transfer to new foliage pool is one-half maximum (t/ha)

G_{46} = new foliage growth demand ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{46} = \max \{B_{38}B_{71}G_{39}[B_{37}(X_{38} + G_{44}) - X_{10}], 0\}$$

X_{10} = new foliage carbon (t/ha)
X_{38} = bud carbon--previous year (t/ha)
G_{39} = temperature effect on growth processes (dim.)
G_{44} = change in last year's bud carbon (t/ha)
B_{37} = ratio of leaf carbon mass to bud carbon (dim.)

B_{38} = rate at which new foliage growth demand decreases as new foliage carbon mass approaches the limiting value (wk^{-1})
B_{71} = factor such that $B_{71}G_{39}$ averages 1.0 during the first-year growing season (dim.)

G_{47} = surplus or deficit new foliage photosynthate after new foliage respiration is satisfied ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{47} = G_{24} - G_{25}$$

G_{24} = net new foliage photosynthesis
G_{25} = new foliage nighttime respiration

G_{48} = average weekly 24-hr air temperature (deg)

$$G_{48} = S_3(6, Z_3)$$

S_3 = weekly averaging function
Z_3 = average 24-hr air temperature (deg)

G_{49} = average weekly stomatal resistance of new foliage (sec/cm)

$$G_{49} = S_3(1, G_{43})$$

G_{43} = new foliage stomatal resistance (sec/cm)
S_3 = weekly averaging function

G_{50} = effect of moisture and temperature on soil rooting zone processes (dim.)

$$G_{50} = \frac{G_{53}X_3}{B_{67}}$$

X_3 = rooting zone water (m^3/ha)
G_{53} = effect of soil temperature on soil processes (dim.)
B_{67} = factor such that G_{50} averages 1.0 during the first year (m^3/ha)

G_{51} = soil temperature (deg)

$$G_{51} = X_{26}$$

X_{26} = soil temperature (deg)

Comment: Soil temperature is updated weekly in this version of the model and daily in other versions. G_{51} is weekly temperature in both versions. See G_{41}.

G_{52} = old foliage stomatal resistance (sec/cm)

$$G_{52} = B_{60}G_{43}$$

G_{43} = new foliage resistance (sec/cm)
B_{60} = ratio of old to new foliage stomatal resistance (dim.)

Comment: Includes both stomatal and mesophyll resistance.

G_{53} = effect of soil temperature on soil processes (dim.)

$$G_{53} = B_{54}S_2(G_{51}, 0, B_{178}, B_{179})$$

G_{51} = weekly average soil temperature (deg)
S_2 = beta function
B_{54} = factor such that G_{53} averages 1.0 during the first year ($deg^{-B_{179}}$)
B_{178} = temperature above which soil rooting zone processes cease (deg)
B_{179} = coefficient for temperature effect on soil rooting zone processes (dim.)

G_{54} = precipitation as rain ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{54} = \begin{cases} 0 & \text{if } Z_6 < B_{19} \\ Z_1 & \text{if } Z_7 > B_{17} \\ T_1 + T_2 & \text{if } Z_6 \le B_{17} \text{ and } Z_7 \ge B_{19} \\ T_1 & \text{if } B_{19} < Z_6 \le B_{17} \text{ and } \\ & \quad Z_7 \le B_{17} \\ Z_1 Z_4 + T_2 & \text{if } Z_6 > B_{17} \ge Z_7 \ge B_{19} \end{cases}$$

$$T_1 = B_{15}Z_1Z_4(Z_6 - B_{19})$$

$$T_2 = B_{15}Z_1(1 - Z_4)(Z_7 - B_{19})$$

Z_1 = total precipitation ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
Z_4 = day length (dim.)
Z_6 = average daytime temperature (deg)
Z_7 = average nighttime temperature (deg)
B_{15} = increase in ratio of rainfall to total precipitation with temperature (deg^{-1})
B_{17} = temperature above which all precipitation is rain (deg)
B_{19} = temperature below which all precipitation is snow (deg)

Comment: This is a linearization of a function for ratio of rainfall to snowfall taken from U.S. Army Corps of Engineers (1956). Their data were for the Willamette Basin Snow Laboratory at Blue River--very near the H. J. Andrews Experimental Forest. We have modified their function to make use of day and night temperatures.

G_{55} = water-holding capacity of litter (m^3/ha)

$$G_{55} = (B_{74}X_{18} + X_{19} + X_{20})B_{23}$$

X_{18} = woody litter carbon (t/ha)
X_{19} = leaf litter carbon (t/ha)

X_{20} = fine litter carbon (t/ha)
B_{23} = ratio of litter water-holding capacity to litter carbon mass (m^3/t)
B_{74} = water-holding capacity per unit carbon mass for woody litter divided by same ratio for foliage and fine litter (dim.)

Comment: We set B_{74} to 0.25 since we assume woody litter holds less water than fine or foliage litter; the actual value is a guess.

G_{56} = drip from epiphyte and bark surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{56} = \max \{0, T_1[X_8 - G_{16}(1 - G_{57})] + [G_4 - (1 - G_{57})G_6](1 - \frac{T_1}{B_{170}})\}$$

$$T_1 = 1 - \exp(-B_{170})$$

X_8 = water storage on epiphyte and bark surfaces (m^3/ha)
G_4 = rain input to epiphyte and bark surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_6 = potential evaporation from canopy ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{16} = water retention capacity of canopy (m^3/ha)
G_{57} = fraction of water retention capacity of canopy due to foliage (dim.)
B_{170} = rate constant for water drainage from canopy (dim.)

Comment: See discussion of G_5, which is analogous.

G_{57} = fraction of water retention capacity of canopy due to foliage (dim.)

$$G_{57} = \frac{G_{61}}{G_{61} + B_{173}X_{13}}$$

X_{13} = stem carbon (t/ha)
G_{61} = total foliage carbon (t/ha)
B_{173} = ratio of storage capacity to carbon mass for stems plus branches divided by same ratio for foliage (dim.)

Comment: The fraction of canopy storage capacity due to bark and epiphyte surfaces is:

$$\frac{B_{173}X_{13}}{G_{61} + B_{173}X_{13}} = 1 - G_{57}$$

See also G_{16}.

G_{58} = average weekly stomatal resistance of old foliage (sec/cm)

$$G_{58} = S_3(7, G_{52})$$

G_{52} = stomatal resistance of old foliage (sec/cm)
S_3 = averaging function

G_{59} = net shortwave radiation at top of canopy (ly/day)

$$G_{59} = 1440(1 - B_{160})Z_2 Z_4$$

Z_2 = incident shortwave radiation (ly/min)
Z_4 = day length (dim.)
B_{160} = albedo of canopy (dim.)

Comment: Average shortwave radiation during the time the sun is shining is converted into total shortwave radiation for the day by multiplying by the number of minutes of daylight ($1440Z_4$).

G_{60} = snowpack ice plus current day's snowfall (m^3/ha)

$$G_{60} = X_2 + G_{115}$$

X_2 = snowpack ice (m^3/ha)
G_{115} = precipitation as snow ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

G_{61} = total foliage carbon (t/ha)

$$G_{61} = X_{10} + X_{11}$$

X_{10} = new foliage carbon (t/ha)
X_{11} = old foliage carbon (t/ha)

G_{62} = carbon transfer from stems plus branches to log litter ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{62} = (1 - B_{150})B_{51}X_{13}$$

X_{13} = stem-plus-branch carbon (t/ha)
B_{51} = rate constant for stem-plus-branch mortality (wk^{-1})
B_{150} = fraction of stem-plus-branch mortality transferred to woody litter (dim.)

G_{67} = change in litter temperature (deg/wk)

$$G_{67} = \begin{cases} \min(1, T_1)(G_{48} - X_{25}) & X_2 < 100 \\ 3.0 - X_{25} & X_2 \geq 100 \end{cases}$$

T_1 = lag effect of air temperature on litter temperature:

$$T_1 = B_{92}(1 + G_{80}/B_{93})$$

X_2 = snowpack ice (m^3/ha)
X_{25} = litter temperature (deg)
G_{48} = average weekly air temperature (deg)
G_{80} = total weekly direct rainfall plus drip ($m^3 \cdot ha^{-1} \cdot wk^{-1}$)
B_{92} = factor for effect of air temperature on litter temperature (wk^{-1})
B_{93} = weekly throughfall amount above which litter temperature equals air temperature ($m^3 \cdot ha^{-1} \cdot wk^{-1}$)

Comment: Changes in litter temperature reflect changes in air temperature with litter temperature changes lagging behind. To accomplish this a lag factor T_1 is incorporated and litter temperature is updated weekly. High rainfall will cause litter temperature to equilibrate to air temperature, since $(1 + G_{80}/B_{93})$ increases with increasing rain. This increases T_1 and thus increases the effect of Z_3 on G_{41}.

G_{68} = change in soil temperature (deg/wk)

$$G_{68} = \min(1, T_1)(X_{25} - X_{26})$$

$$T_1 = B_{95}(1 + G_{80}/B_{73})$$

X_{25} = litter temperature (deg)
X_{26} = soil temperature (deg)
G_{80} = total weekly direct rainfall plus drip ($m^3 \cdot ha^{-1} \cdot wk^{-1}$)
B_{73} = weekly throughfall amount above which soil temperature equals air temperature ($m^3 \cdot ha^{-1} \cdot wk^{-1}$)
B_{95} = lag coefficient for effect of litter temperature upon soil temperature (wk^{-1})

G_{69} = effect of moisture and temperature on litter processes (dim.)

$$G_{69} = \begin{cases} B_{94}X_7G_{77} & X_7 < G_{55} \\ B_{94}G_{55}G_{77} & X_7 \geq G_{55} \end{cases}$$

X_7 = litter water (m^3/ha)
G_{55} = water-holding capacity of litter (m^3/ha)
G_{77} = effect of temperature on litter processes (dim.)
B_{94} = constant such that G_{69} averages 1.0 during the first year (ha/m^3)

Comment: Effect increases linearly with moisture until holding capacity is reached. Above holding capacity, effect does not change with litter moisture.

G_{70} = rainfall passing directly to litter surface ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{70} = \begin{cases} 0 & G_{60} > 0 \\ G_9 & G_{60} \leq 0 \end{cases}$$

G_9 = rainfall passing directly to snowpack or litter surface ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{60} = snowpack ice plus current day's snowfall (m^3/ha)

G_{71} = drip from foliar surfaces to litter surface water ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{71} = \begin{cases} G_5 & \text{if } G_{60} \leq 0 \\ 0 & \text{if } G_{60} > 0 \end{cases}$$

G_5 = drip from foliar surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{60} = snowpack ice plus current day's snowfall (m^3/ha)

G_{72} = drip from epiphyte and bark surfaces to litter surface water ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{72} = \begin{cases} G_{56} & \text{if } G_{60} \leq 0 \\ 0 & \text{if } G_{60} > 0 \end{cases}$$

G_{56} = drip from epiphyte and bark surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{60} = snowpack ice plus current day's snowfall (m^3/ha)

G_{74} = rainfall passing directly to free water in snowpack ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{74} = \begin{cases} G_9 & G_{60} > 0 \\ 0 & G_{60} \leq 0 \end{cases}$$

G_9 = rainfall passing directly to snowpack or litter surface ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{60} = snowpack ice plus current day's snowfall (m^3/ha)

G_{75} = drip from foliar surfaces to free water in snowpack ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{75} = \begin{cases} G_5 & \text{if } G_{60} > 0 \\ 0 & \text{if } G_{60} \leq 0 \end{cases}$$

G_5 = drip from foliar surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{60} = snowpack ice plus current day's snowfall (m^3/ha)

G_{76} = drip from epiphyte and bark surfaces to free water in snowpack ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{76} = \begin{cases} G_{56} & \text{if } G_{60} > 0 \\ 0 & \text{if } G_{60} \leq 0 \end{cases}$$

G_{56} = drip from epiphyte and bark surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{60} = snowpack ice plus current day's snowfall (m^3/ha)

G_{77} = effect of litter temperature on litter processes (dim.)

$$G_{77} = B_{24} S_2 (G_{41}, 0, B_{180}, B_{181})$$

G_{41} = litter temperature (deg)
S_2 = beta function
B_{24} = factor such that G_{77} averages 1.0 during the first year ($deg^{-B_{181}}$)
B_{180} = temperature above which litter decomposition ceases (deg)
B_{181} = coefficient for temperature effect on litter decomposition (dim.)

G_{78} = total respiration loss from growth CH_2O pool ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{78} = G_{30} + G_{31}$$

G_{30} = old foliage nighttime respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{31} = total nonfoliar plant respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

G_{79} = carbon transfer from buds to new foliage $(t \cdot ha^{-1} \cdot wk^{-1})$

$$G_{79} = \begin{cases} X_{16} - G_{95} + G_{33} & \text{if } t_W = M_1 \\ 0 & \text{otherwise} \end{cases}$$

X_{16} = bud carbon--current year (t/ha)
G_{33} = bud growth $(t \cdot ha^{-1} \cdot wk^{-1})$
G_{95} = bud consumption by insects $(t \cdot ha^{-1} \cdot wk^{-1})$
M_1 = week on which bud break occurs
t_W = time (wk modulo 52)

Comment: All bud carbon becomes new foliage at the start of the growing season. Bud growth and losses that week are taken into account.

G_{80} = total weekly direct rainfall plus drip $(m^3 \cdot ha^{-1} \cdot wk^{-1})$

$$G_{80} = 7S_3(12, G_{134})$$

G_{134} = total water input to snowpack or litter $(m^3 \cdot ha^{-1} \cdot day^{-1})$
S_3 = averaging function

Comment: S_3 gives weekly average which we multiply by 7 to get weekly total.

G_{81} = foliage litter decomposition rate $(t \cdot ha^{-1} \cdot wk^{-1})$

$$G_{81} = B_{62}G_{69}X_{19}$$

X_{19} = foliage litter carbon (t/ha)
G_{69} = effect of moisture and temperature on litter processes (dim.)
B_{62} = rate constant for foliage litter decomposition (wk^{-1})

G_{82} = insect frass input to fine litter $(t \cdot ha^{-1} \cdot wk^{-1})$

$$G_{82} = B_{75}X_{17}$$

X_{17} = canopy insect carbon (t/ha)
B_{75} = rate constant for frass fall (wk^{-1})

Comment: Here B_{75} is based on an estimate by Strand (1974).

G_{83} = woody litter decomposition rate $(t \cdot ha^{-1} \cdot wk^{-1})$

$$G_{83} = B_{61}G_{69}X_{18}$$

X_{18} = woody litter carbon (t/ha)
G_{69} = effect of moisture and temperature on litter processes (dim.)
B_{61} = rate constant for woody litter decomposition (wk^{-1})

G_{84} = fine litter decomposition rate ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{84} = B_{63}G_{69}X_{20}$$

X_{20} = fine litter carbon (t/ha)
G_{69} = effect of moisture and temperature on litter processes (dim.)
B_{63} = rate constant for fine litter decomposition (wk^{-1})

G_{85} = dead root decomposition rate ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{85} = B_{68}G_{50}X_{62}$$

X_{62} = dead root carbon (t/ha)
G_{50} = effect of moisture and temperature on soil rooting zone processes (dim.)
B_{68} = rate constant for dead root decomposition (wk^{-1})

G_{86} = large root mortality ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{86} = B_{52}X_{14}$$

X_{14} = large root carbon (t/ha)
B_{52} = rate constant for large root mortality (wk^{-1})

<u>Comment</u>: Since large root biomass varies little during the year, large root mortality is nearly constant.

G_{87} = fine root mortality ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{87} = \frac{B_{53}X_{15}G_{42}}{B_{78}}$$

X_{15} = fine root carbon (t/ha)
G_{42} = plant moisture stress (PMS; atm)
B_{53} = rate constant for fine root mortality (wk^{-1})
B_{78} = minimum PMS (atm)

<u>Comment</u>: Mortality rate increases linearly with moisture stress. The constant B_{78} simply normalizes the rate constant so that it is comparable to B_{52} and B_{51}.

G_{88} = rooting zone carbon decomposition rate ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{88} = B_{65}G_{50}X_{21}$$

X_{21} = rooting zone carbon (t/ha)
G_{50} = effect of moisture and temperature on soil rooting zone processes (dim.)
B_{65} = rate constant for decomposition of soil rooting zone carbon (wk^{-1})

G_{90} = old foliage consumption by insects ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{90} = B_{57}X_{11}G_{39}$$

X_{11} = old foliage carbon (t/ha)
G_{39} = temperature effect on growth processes (dim.)
B_{57} = rate constant for old foliage consumption (wk^{-1})

G_{91} = shortwave radiation incident to litter or snowpack (ly/day)

$$G_{91} = G_{59}T_1[1 - G_{23}(1 - T_2)]$$

T_1 = fraction of incident light transmitted through understory

$$T_1 = \exp\ [-B_1G_{61}(1 - B_4)]$$

T_2 = fraction of incident light transmitted through overstory

$$T_2 = \exp\ [-B_2G_{61}B_4]$$

G_{23} = percent cover by overstory (see comment below; dim.)
G_{59} = net shortwave radiation at top of canopy (ly/day)
G_{61} = total foliage carbon (t/ha)
B_1 = coefficient for attenuation of shortwave radiation by understory (ha/t)
B_2 = coefficient for attenuation of shortwave radiation by overstory (ha/t)
B_4 = fraction of total foliage occurring in the overstory (dim.)

Comment: Originally we lumped overstory and understory together and calculated attenuation according to Beer's law; however, since understory is largely broad-leaved, it has different attenuation characteristics from the overstory. Also, a fraction of the shortwave radiation incident to the canopy ($1 - G_{23}$) passes unattenuated to the understory. This results in radiation incident to the forest floor depending upon both the total foliage biomass $X_{10} + X_{11}$ (both directly and via G_{59}, which also depends indirectly upon $X_{10} + X_{11}$) and upon the fraction of total foliage in the overstory. Here G_{23} is fraction of total incident shortwave radiation attenuated by the overstory while for rainfall it is the fraction of rainfall hitting the entire canopy (overstory plus understory).

G_{92} = carbon transfer from stems plus branches to woody litter ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{92} = B_{150}B_{51}X_{13}$$

X_{13} = stem-plus-branch carbon (t/ha)
B_{51} = rate constant for stem-plus-branch mortality (wk^{-1})
B_{150} = fraction of stem-plus-branch mortality transferred to woody litter (dim.)

G_{93} = acute old foliage defoliation ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{93} = S_6(B_{185},\ B_{186},\ B_{184}X_{11})$$

X_{11} = old foliage carbon (t/ha)
S_6 = delta function
B_{184} = fraction by which old foliage is reduced during acute defoliation perturbation (dim.)
B_{185} = first day on which old foliage is removed
B_{186} = second day on which old foliage is removed

Comment: See comments for G_{40}, G_{44}.

G_{94} = consumption of growth CH_2O pool by insects ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{94} = B_{58} X_{12} G_{39}$$

X_{12} = carbon in growth CH_2O pool (t/ha)
G_{39} = temperature effect on growth processes (dim.)
B_{58} = rate constant for consumption of growth CH_2O pool by insects (wk^{-1})

Comment: Temperature effect makes consumption vary seasonally.

G_{95} = bud consumption by insects ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{95} = B_{59} X_{16} G_{39}$$

X_{16} = bud carbon--current year (t/ha)
G_{39} = temperature effect on growth processes (dim.)
B_{59} = rate constant for bud consumption (wk^{-1})

G_{97} = input to fine litter from microparticulate matter and carbon dissolved in precipitation ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{97} = B_{152}$$

B_{152} = rate of input of carbon to fine litter in microparticulate matter and carbon dissolved in precipitation ($t \cdot ha^{-1} \cdot wk^{-1}$)

G_{98} = carbon loss from foliage litter due to fragmentation ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{98} = B_{149} G_{81}$$

G_{81} = foliage litter decomposition rate ($t \cdot ha^{-1} \cdot wk^{-1}$)
B_{149} = fraction of carbon loss from foliage litter due to fragmentation (dim.)

Comment: Ratio of fragmentation loss to respiration loss is assumed constant.

G_{99} = vapor pressure deficit (mbar•joule•m^{-3}•deg^{-1})

$$G_{99} = [G_{21} - S_1(Z_5)]B_{154}B_{155}$$

G_{21} = saturation vapor pressure at air temperature (mbar)
Z_5 = average 24-hr dew point temperature (deg)
$S_1(Z_5)$ = actual vapor pressure - saturation vapor pressure at dew point temperature Z_5 (mbar)
B_{154} = density of saturated air (kg/m^3)
B_{155} = specific heat of saturated air (joule•kg^{-1}•deg^{-1})

G_{100} = aerodynamic resistance (sec/m)

$$G_{100} = \begin{cases} (Z_{14}B_{156}{}^2)^{-1} & \text{if } Z_{14} \neq 0 \\ 10^6 & \text{if } Z_{14} = 0 \end{cases}$$

Z_{14} = wind speed (m/sec)
B_{156} = wind profile drag coefficient (dim.)

Comment: The wind profile drag coefficient is a composite coefficient dependent upon von Karman's constant, the height at which wind speed is measured, and the average height of the vegetation (see Rutter et al. 1971). Note that, if $Z_{14} = 0$, G_{100} is set equal to a large, arbitrary number.

G_{101} = canopy resistance (sec/m)

$$G_{101} = \frac{(G_{43}X_{10} + G_{52}X_{11})100}{G_{61}}$$

X_{10} = new foliage carbon (t/ha)
X_{11} = old foliage carbon (t/ha)
G_{43} = new foliage stomatal resistance (sec/cm)
G_{52} = old foliage stomatal resistance (sec/cm)
G_{61} = total foliage carbon (t/ha)

Comment: Canopy resistance is weighted average of old and new foliage resistances. The 100 converts sec/cm to sec/m as needed for Penman's equation.

G_{102} = effect of temperature on photosynthesis (deg$^{B_{177}}$)

$$G_{102} = S_2(G_{107}, 0, B_{176}, B_{177})$$

G_{107} = average weekly daytime air temperature (deg)
S_2 = beta function
B_{176} = temperature above which photosynthesis ceases (deg)
B_{177} = coefficient determining shape of G_{102} (dim.)

Comment: See G_{24} for graph.

G_{103} = carbon loss from foliage litter due to respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{103} = (1 - B_{149})G_{81}$$

G_{81} = foliage litter decomposition rate ($t \cdot ha^{-1} \cdot wk^{-1}$)
B_{149} = carbon loss from fraction of foliage litter due to fragmentation (dim.)

G_{104} = carbon loss from woody litter due to fragmentation ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{104} = B_{148}G_{83}$$

G_{83} = woody litter decomposition rate ($t \cdot ha^{-1} \cdot wk^{-1}$)
B_{148} = fraction of carbon loss from woody litter due to fragmentation (dim.)

G_{105} = log litter decomposition rate ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{105} = B_{146}X_9G_{77}$$

X_9 = log litter carbon (t/ha)
G_{77} = effect of temperature on litter processes (dim.)
B_{146} = rate constant for log litter decomposition (wk^{-1})

G_{106} = phenology of tree growth

$$G_{106} = \begin{cases} 0 & \text{if } t_w < M_2 \text{ or } t_w \geq M_3 \\ 1 & \text{otherwise} \end{cases}$$

M_2 = week on which growing season starts
M_3 = week on which growing season ends
t_w = time (wk modulo 52)

Comment: G_{106} is 1 during the growing season, zero otherwise.

G_{107} = average weekly daytime air temperature (deg)

$$G_{107} = S_3(4, Z_6)$$

Z_6 = daily daytime air temperature (deg)
S_3 = weekly averaging function

G_{108} = average weekly nighttime air temperature (deg)

$$G_{108} = S_3(5, Z_7)$$

Z_7 = average nighttime temperature (deg)
S_3 = weekly averaging function

G_{109} = average weekly photosynthetically active radiation (ly/min)

$$G_{109} = B_{183}S_3(2, Z_2)$$

Z_2 = average shortwave radiation (ly/min)
S_3 = weekly averaging function
B_{183} = ratio of photosynthetically active radiation to total shortwave radiation (dim.)

G_{110} = average weekly day length (dim.)

$$G_{110} = S_3(3, Z_4)$$

Z_4 = day length (dim.)
S_3 = weekly averaging function

G_{111} = carbon loss from woody litter due to respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{111} = (1 - B_{148})G_{83}$$

G_{83} = woody litter decomposition rate ($t \cdot ha^{-1} \cdot wk^{-1}$)
B_{148} = fraction of carbon loss from woody litter due to fragmentation (dim.)

G_{112} = carbon loss from log litter due to fragmentation ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{112} = B_{147}G_{105}$$

G_{105} = log litter decomposition rate ($t \cdot ha^{-1} \cdot wk^{-1}$)
B_{147} = fraction of carbon loss from log litter due to fragmentation (dim.)

G_{113} = carbon loss from log litter due to respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{113} = (1 - B_{147})G_{105}$$

G_{105} = log litter decomposition rate ($t \cdot ha^{-1} \cdot wk^{-1}$)
B_{147} = fraction of carbon loss from log litter due to fragmentation (dim.)

G_{114} = heat input to snowpack due to snowfall (ly/day)

$$G_{114} = \min(0, 0.005 Z_3 G_{115})$$

G_{115} = precipitation as snow ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
Z_3 = average 24-hr air temperature (deg)

<u>Comment:</u> The specific heat of ice = 0.5 $cal \cdot cm^{-3} \cdot deg^{-1}$ = 0.5×10^6 $cal \cdot m^{-3} \cdot deg^{-1}$. We then multiply by 10^{-8} ha/cm^2 to get 0.005 $ly \cdot ha \cdot m^{-3} \cdot deg^{-1}$. Snowfall may occur when air temperature is above zero but we assume falling snow will be at 0°C.

G_{115} = precipitation as snow ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{115} = Z_1 - G_{54}$$

G_{54} = precipitation as rain ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
Z_1 = total precipitation ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

G_{116} = incorporation of fine litter into rooting zone organic matter

$$G_{116} = B_{64} G_{84}$$

G_{84} = fine litter decomposition rate ($t \cdot ha^{-1} \cdot wk^{-1}$)
B_{64} = fraction of carbon loss from fine litter due to incorporation into soil rooting zone organic matter (dim.)

G_{117} = heat input to snowpack due to rainfall (ly/day)

$$G_{117} = 0.01 Z_3 G_{134}$$

G_{134} = total water input to snowpack or litter ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
Z_3 = average 24-hr air temperature (deg)

Comment: Specific heat of water = 1 $cal \cdot cm^{-3} \cdot deg^{-1}$ which is converted to 0.01 $ly \cdot ha \cdot m^{-3} \cdot deg^{-1}$ as with G_{114}.

G_{118} = albedo of snowpack or litter (dim.)

$$G_{118} = S_5$$

$$S_5 = \begin{cases} T_1(t_d - T_2) & \text{if } G_{115} = 0 \text{ and } t_d - T_2 \leq 40 \\ 0.4 & \text{if } t_d - T_2 > 40 \text{ and } G_{115} = 0 \\ 0.8 & \text{if } Z_6 \leq B_6 \text{ and } G_{115} > 0 \\ 0.91 & \text{if } G_{160} < 0 \text{ and } G_{115} > 0 \\ 0.81 & \text{if } G_{160} \geq 0 \text{ and } G_{115} > 0 \\ 0.1 & \text{if } X_2 \leq 10 \end{cases}$$

T_1 = table look-up function for albedo as function of time since last snow, range is 0.8 to 0.4 (dim.)
T_2 = time of most recent snowfall (day)
X_2 = snowpack ice (m^3/ha)
G_{115} = precipitation as snow ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{160} = snow surface temperature (deg)
Z_6 = average daytime air temperature (deg)
B_6 = temperature threshold below which albedo of snowpack is set equal to 0.8 (deg)
t_d = time (day)

Comment: T_2 is called INT in code. See Leaf and Brink (1973). Albedo of the snowpack depends upon the time since the last snowfall ($t_d - T_2$) and whether the snowpack is accumulating or melting. This is determined by looking at air temperature and snow temperature. If daytime air temperature is below B_6 (3°C), or snow temperature is less than zero, or it is snowing, then we assume an accumulating phase; otherwise we assume a melting phase and albedo drops with increasing time since the last snow. When there is no snow on the ground, litter albedo is used.

G_{119} = net heat transfer through canopy to snowpack or litter due to shortwave radiation (ly/day)

$$G_{119} = (1 - G_{118})G_{91}$$

G_{91} = shortwave radiation incident to litter layer or snowpack (ly/day)
G_{118} = albedo of snowpack or litter (dim.)

Comment: Includes shortwave light penetrating directly through gaps in canopy. Reflection from litter or snowpack is also taken into account.

G_{120} = net heat input to snowpack or litter due to longwave radiation (ly/day)

$$G_{120} = G_{124} + (1 - G_{23})(G_{123} - G_{121})$$

G_{23} = percent cover by canopy (dim.)
G_{121} = heat loss from snowpack or litter due to longwave radiation (ly/day)
G_{123} = longwave radiation from sky (ly/day)
G_{124} = net heat transfer from canopy to snowpack or litter due to longwave radiation (ly/day)

G_{121} = heat loss from snowpack or litter due to longwave radiation (ly/day)

$$G_{121} = \begin{cases} S_4(G_{160}) & \text{if } X_2 > 0 \\ S_4(X_{25}) & \text{if } X_2 \leq 0 \end{cases}$$

X_2 = snowpack ice (m^3/ha)
X_{25} = litter temperature (deg)
G_{160} = snow surface temperature (deg)
S_4 = longwave radiation from blackbody (ly/day)

Comment: If there is snow on the ground it is assumed to radiate as a blackbody at its surface temperature G_{160}. If there is no snow ($X_2 < 10$) the forest floor emits at litter temperature X_{25}.

G_{122} = longwave radiation from blackbody at air temperature (ly/day)

$$G_{122} = S_4(Z_3)$$

Z_3 = air temperature (deg)
S_4 = longwave radiation from blackbody (ly/day)

G_{123} = longwave radiation from sky

$$G_{123} = T_3 G_{122}$$

$$T_1 = \sin\,[0.01721(t_d - 79.01721)]$$

T_2 = day length at latitude of study site (dim.)

$$T_2 = \frac{B_{25}T_1 + 12}{24}$$

T_3 = factor for effective transmission by sky = 1 for cloudy day and 0.76 for clear day (dim.)

$$T_3 = \begin{cases} 0.76 & \text{if } Z_2 > 1.6T_2 \\ 1 & \text{if } Z_2 < T_2 \\ 0.76 + 0.4[(1.6T_2 - Z_2)/T_2] & \text{if } T_2 < Z_2 \leq 1.6T_2 \end{cases}$$

G_{122} = longwave radiation from blackbody at air temperature (ly/day)
Z_2 = average shortwave radiation (ly/min)
B_{25} = length of longest day minus twelve (hr)
t_d = time (day)

Comment: The function T_2 calculates day length for the latitude and longitude of WS-10 as a function of day of year. Here T_3 adjusts heat transfer from sky to canopy depending on whether the day is clear, cloudy, or partly cloudy (U.S. Army Corps of Engineers 1956). Cloud cover is estimated by comparing incident shortwave radiation Z_2 with radiation values typical of clear and cloudy days. We assumed that for a day of average day length (T_2 [avg] = 0.5), a cloudy day would have $Z_2 < 0.5$ ly/min while a clear day would have $Z_2 > 0.8$ ly/min. Adjusting for changing day length we test instead for $Z_2 < 0.5T_2/T_2$ (avg) and $Z_2 > 0.8T_2/T_2$ (avg) or $Z_2 < T_2$ and $Z_2 > 1.6T_2$, respectively.

We assumed that on a clear day radiation from the sky was 76% of that emitted from a blackbody at air temperature, and that this percentage increased with increasing cloudiness until for a fully cloudy day it was 100%.

G_{124} = net heat transfer from canopy to snowpack or litter due to longwave radiation (ly/day)

$$G_{124} = G_{23}(G_{122} - G_{121})$$

G_{23} = percent cover by canopy (dim.)
G_{121} = heat loss from snowpack or litter due to longwave radiation (ly/day)
G_{122} = longwave radiation from blackbody at air temperature (ly/day)

Comment: We assume the canopy radiates as a blackbody at air temperature.

G_{125} = carbon loss from fine litter due to respiration

$$G_{125} = (1 - B_{64})G_{84}$$

G_{84} = fine litter decomposition rate ($t \cdot ha^{-1} \cdot wk^{-1}$)
B_{64} = fraction of carbon loss from fine litter due to incorporation into soil rooting zone organic matter (dim.)

G_{126} = carbon loss from dead roots due to fragmentation

$$G_{126} = B_{69}G_{85}$$

G_{85} = dead root decomposition rate ($t \cdot ha^{-1} \cdot wk^{-1}$)
B_{69} = fraction of carbon loss from dead roots due to fragmentation (dim.)

G_{127} = net heat input to snowpack (ly/day)

$$G_{127} = G_{114} + G_{117} + G_{119} + G_{120} + G_2 + G_{170}$$

G_2 = heat input to snow due to condensation (ly/day)
G_{114} = heat input to snowpack due to snowfall (ly/day)
G_{117} = heat input to snowpack due to rainfall (ly/day)
G_{119} = net heat transfer through canopy to snowpack or litter due to shortwave radiation (ly/day)
G_{120} = net heat input to snowpack or litter due to longwave radiation (ly/day)
G_{170} = heat input to snowpack due to convection (ly/day)

G_{128} = net increase in heat deficit of snowpack (ly/day)

$$G_{128} = \begin{cases} \max \begin{cases} -X_{37} \\ -G_{127} - 0.8(G_{134} + X_{98}) \end{cases} & \text{if } G_{60} > 0 \\ 0 & \text{if } G_{60} \leq 0 \end{cases}$$

X_{37} = snowpack heat deficit (ly)
X_{98} = free water in snowpack (m^3/ha)
G_{60} = snowpack ice plus current day's snowfall (m^3/ha)
G_{127} = net heat input to snowpack (ly/day)
G_{134} = total water input to snowpack or litter ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

Comment: This seemingly simple expression masks a complex situation. Initial heat deficit X_{37} (which may be zero) is compared with net heat input to snowpack G_{127} plus potential heat gain ($0.8[G_{134} + X_{98}]$) if all free water in snowpack were to freeze. The smaller of these is the resultant change in heat deficit (the min becomes a max because change in heat deficit is the negative of the heat gain). The 0.8 is the heat of fusion of water ($ly \cdot ha \cdot m^{-3}$).

G_{129} = transfer from ice to free water in snowpack $(m^3 \cdot ha^{-1} \cdot day^{-1})$

$$G_{129} = \min \begin{cases} G_{60} \\ \max \begin{cases} 0 \\ \dfrac{G_{127} - X_{37}}{0.8} \end{cases} \end{cases}$$

X_{37} = snowpack heat deficit (ly)
G_{60} = snowpack ice plus current day's snowfall (m^3/ha)
G_{127} = net heat input to snowpack (ly/day)

Comment: There is no snowmelt unless there is a daily heat gain greater than the initial heat deficit. There must of course be snow to melt. If $G_{127} > X_{37}$ then the quantity $(G_{127} - X_{37})/0.8$ (net heat input to snowpack minus initial heat deficit converted to water equivalent) is compared with the total snow ice available to melt and the smaller of these melts. The 0.8 is the heat of fusion of water $(ly \cdot ha \cdot m^{-3})$.

G_{130} = free water holding capacity of snowpack (m^3/ha)

$$G_{130} = 0.04 G_{60}$$

G_{60} = snowpack ice plus current day's snowfall (m^3/ha)

Comment: Ratio of free water holding capacity to snow ice is from U.S. Army Corps of Engineers (1956, p. 301-304).

G_{131} = carbon loss from dead roots due to respiration $(t \cdot ha^{-1} \cdot wk^{-1})$

$$G_{131} = (1 - B_{69}) G_{85}$$

G_{85} = dead root decomposition rate $(t \cdot ha^{-1} \cdot wk^{-1})$
B_{69} = fraction of carbon loss from dead roots due to fragmentation (dim.)

G_{132} = carbon transfer from soil rooting zone to subsoil $(t \cdot ha^{-1} \cdot wk^{-1})$

$$G_{132} = B_{66} G_{88}$$

G_{88} = rooting zone organic matter decomposition rate $(t \cdot ha^{-1} \cdot wk^{-1})$
B_{66} = fraction of carbon loss from soil rooting zone due to incorporation into subsoil organic matter (dim.)

G_{133} = carbon loss from rooting zone due to respiration $(t \cdot ha^{-1} \cdot wk^{-1})$

$$G_{133} = (1 - B_{66}) G_{88}$$

G_{88} = rooting zone organic matter decomposition rate $(t \cdot ha^{-1} \cdot wk^{-1})$
B_{66} = fraction of carbon loss from soil rooting zone due to incorporation into subsoil organic matter (dim.)

G_{134} = total water input to snowpack or litter ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{134} = G_9 + G_5 + G_{56}$$

G_5 = drip from foliar surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_9 = rainfall passing directly to snowpack ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{56} = drip from epiphyte and bark surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

G_{135} = transfer from new foliage to leaf litter due to acute defoliation ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{135} = 0.5S_6(B_{166}, B_{169}, B_{167}X_{10})$$

X_{10} = new foliage carbon (t/ha)
S_6 = delta function
B_{166} = first day on which new foliage is to be removed
B_{167} = fraction by which new foliage is to be reduced during acute defoliation perturbation
B_{169} = second day on which new foliage is to be removed

Comment: See G_{40}, G_{44}. We assume this is equal to transfer to fine litter, i.e., one-half is transferred to each. This function is zero-valued unless we desire to see the effect of acute defoliation.

G_{136} = carbon transfer from old foliage to fine litter due to acute defoliation ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{136} = 0.5G_{93}$$

G_{93} = acute old foliage defoliation ($t \cdot ha^{-1} \cdot wk^{-1}$)

G_{138} = stem-plus-branch respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{138} = \frac{B_{28} \exp (B_{141}G_{48})X_{12}}{X_{12} + B_{46}}$$

X_{12} = carbon in growth CH_2O pool (t/ha)
G_{48} = average weekly 24-hr air temperature (deg)
B_{28} = maximum respiration rate of stems plus branches ($t \cdot ha^{-1} \cdot wk^{-1}$)
B_{46} = value of growth pool at which respiration of and transfer to stems plus branches is one-half maximum (t/ha)
B_{141} = coefficient for effect of temperature on plant nonfoliar respiration (deg^{-1})

Comment: The assumption in G_{138}, G_{139}, and G_{140} is that temperature has the same effect ($Q_{10} = 2$) on both above- and belowground plant respiration, although the rates at any given time are not the same since air and soil temperatures are not equal. Also note that stem-plus-branch carbon and large root carbon do not enter into the respiration functions. As the trees grow, the growth CH_2O pool will also increase, resulting in increased respiration.

G_{139} = large root respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{139} = \frac{B_{29} \exp (B_{141}G_{51})X_{12}}{X_{12} + B_{48}}$$

X_{12} = carbon in growth CH_2O pool (t/ha)
G_{51} = average weekly soil temperature (deg)
B_{29} = maximum respiration rate of large roots ($t \cdot ha^{-1} \cdot wk^{-1}$)
B_{48} = value of growth pool at which respiration of and transfer to large roots is one-half maximum (t/ha)
B_{141} = coefficient for effect of temperature on plant nonfoliar respiration (deg^{-1})

Comment: See G_{138}.

G_{140} = fine root respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$G_{140} = \frac{B_{30} \exp (B_{141}G_{51})X_{15}X_{12}}{X_{12} + B_{50}}$$

X_{12} = carbon in growth CH_2O pool (t/ha)
X_{15} = fine root carbon (t/ha)
G_{51} = average weekly soil temperature (deg)
B_{30} = rate constant for fine root respiration (wk^{-1})
B_{50} = value of growth pool at which respiration of and transfer to fine roots in one-half maximum (t/ha)
B_{141} = coefficient for effect of temperature on plant nonfoliar respiration (deg^{-1})

Comment: See G_{138}.

G_{160} = snow surface temperature (deg)

$$G_{160} = 0$$

Comment: We assume snowpack surface temperature is always 0°C but realize that for many other study areas G_{160} must be computed.

G_{161} = freezing of free water in snowpack ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

$$G_{161} = \begin{cases} \min \begin{cases} X_{98} + G_{134} \\ \max \begin{cases} 0 \\ \dfrac{X_{37} - G_{127}}{0.8} \end{cases} \end{cases} & \text{if } G_{60} > 0 \\ 0 & \text{if } G_{60} \leq 0 \end{cases}$$

X_{37} = heat deficit in snowpack (ly)
X_{98} = free water in snowpack (m^3/ha)
G_{60} = snowpack ice plus current day's snowfall (m^3/ha)
G_{127} = net heat input to snowpack (ly/day)
G_{134} = total water input to snowpack or litter ($m^3 \cdot ha^{-1} \cdot day^{-1}$)

Comment: No snow freezes unless the heat deficit at the end of the day (X_{37} - G_{127}) is greater than zero and there is free water available to freeze. In this case the smaller of what could potentially freeze [(X_{37} - G_{127})/0.8] and what is available (X_{98} + G_{134}) actually freezes. The 0.8 is the heat of fusion of water (ly•ha•m^{-3}).

G_{168} = net heat transfer from sky to canopy due to longwave radiation (ly/day)

$$G_{168} = (G_{123} - G_{122})G_{23}$$

G_{23} = percent cover by canopy (dim.)
G_{122} = longwave radiation from blackbody at air temperature (ly/day)
G_{123} = longwave radiation from sky (ly/day)

G_{169} = heat input to canopy due to long- and shortwave radiation (ly/day)

$$G_{169} = G_{168} - G_{124} + G_{59} - G_{119}$$

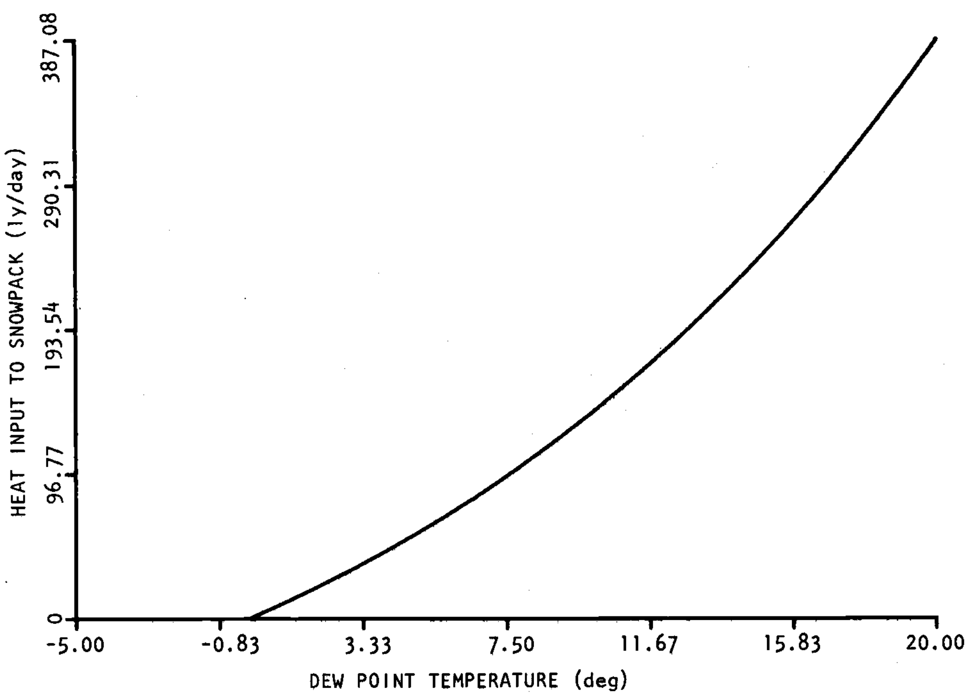
G_{59} = net shortwave radiation at canopy top (ly/day)
G_{119} = net heat transfer through canopy to snowpack or litter due to shortwave radiation (ly/day)
G_{124} = net heat transfer from canopy to snowpack or litter due to longwave radiation (ly/day)
G_{168} = net heat transfer from sky to canopy due to longwave radiation (ly/day)

G_{170} = heat input to snowpack due to convection (ly/day)

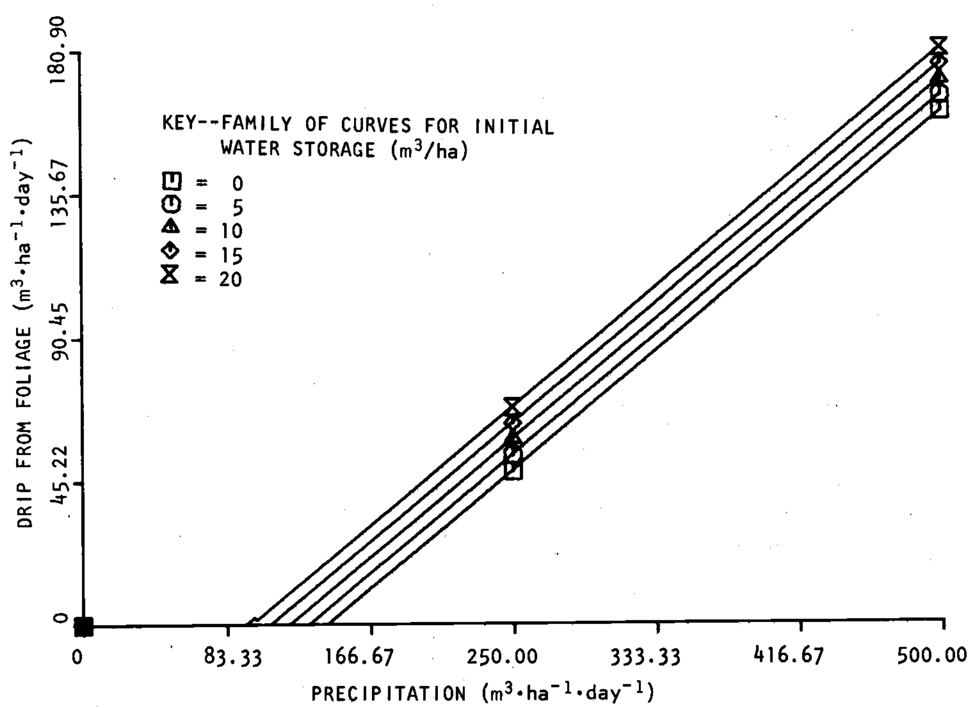
$$G_{170} = \max\,[0,\ 80B_{21}(Z_3 - G_{160})]$$

G_{160} = snow surface temperature (deg)
Z_3 = average 24-hr air temperature (deg)
B_{21} = factor for effect of temperature difference between air and snow on snowmelt due to convection (g•cm^{-2}•day^{-1}•deg^{-1})

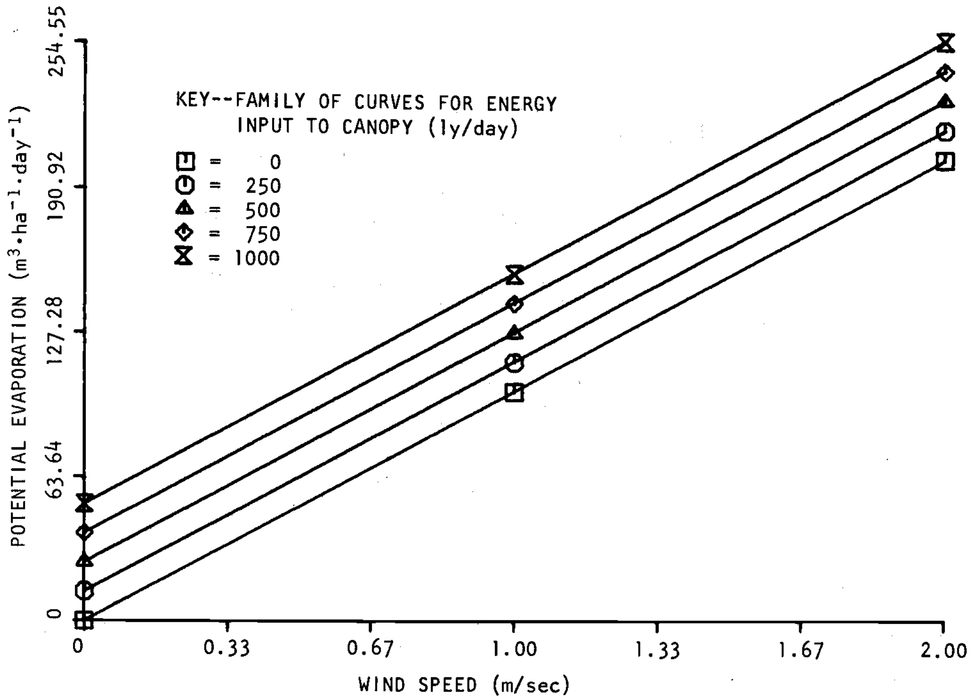
Comment: The relationship in G_{170} is from a regression of temperature difference on snowmelt due to convection based on a four-year study at Willamette Basin Snow Laboratory (U.S. Army Corps of Engineers 1956). Note that 80 is heat of fusion of water (cal/g). Conversion to ly/day was necessary to calculate snowpack heat deficit (X_{37}). The term Z_3 - G_{160} is a measure of the temperature gradient at the pack surface.



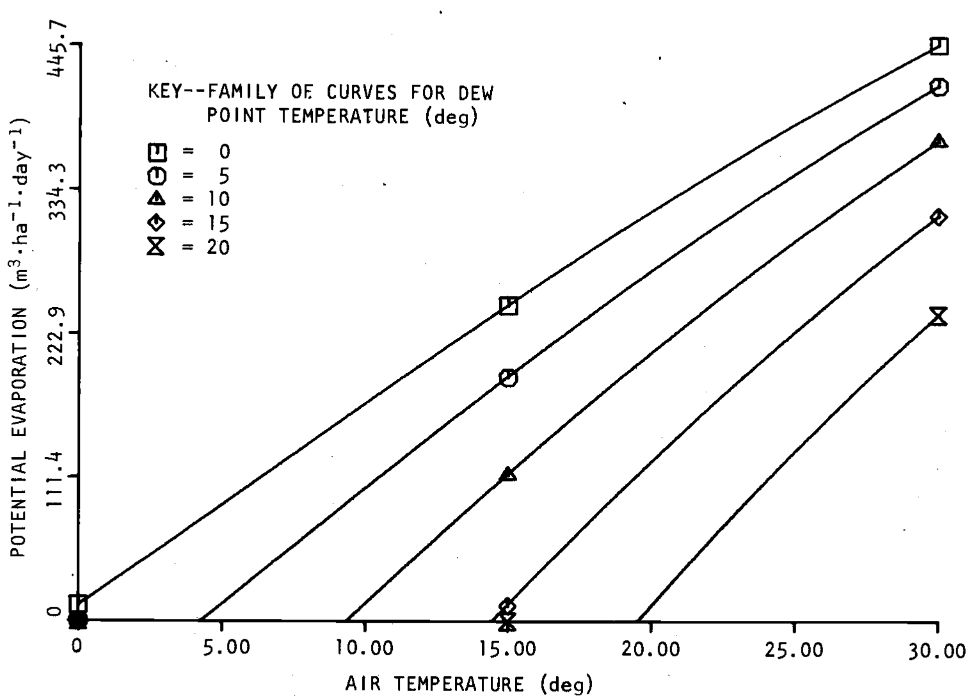
G_2--Heat input to snowpack due to condensation as a function of dew point temperature. Held constant: daily precipitation = 100 m^3/ha, day length = 0.5.



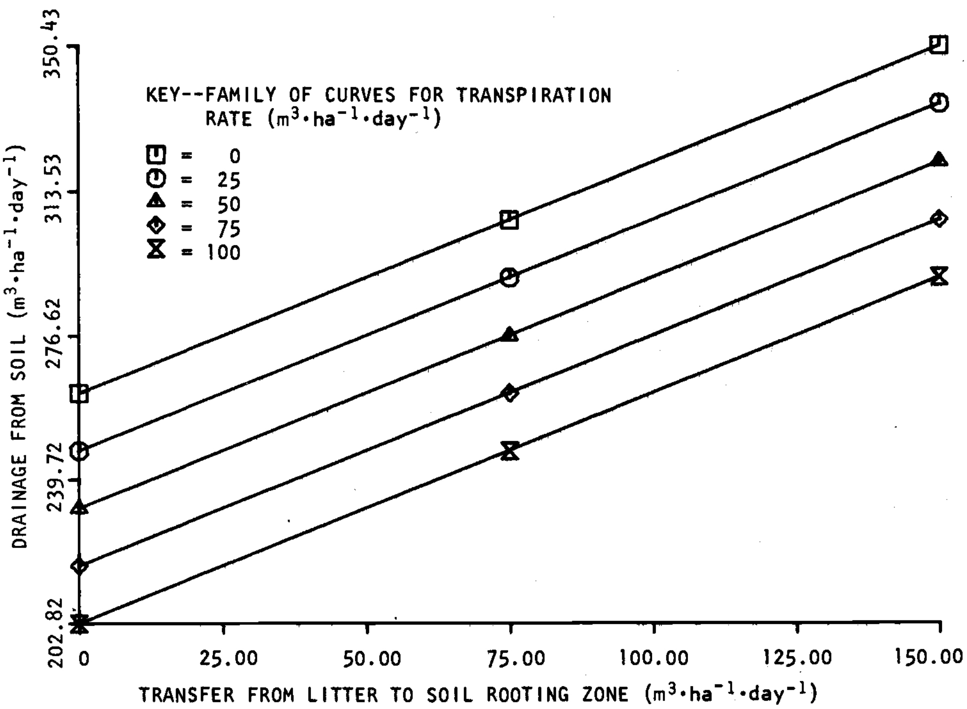
G_5--Drip from foliage as a function of rain input to canopy and initial water storage. Held constant: daily precipitation = 100 m^3/ha, foliage biomass = 5 t/ha, air temperature = 15°C, dew point temperature = 10°C, wind speed = 1 m/sec.



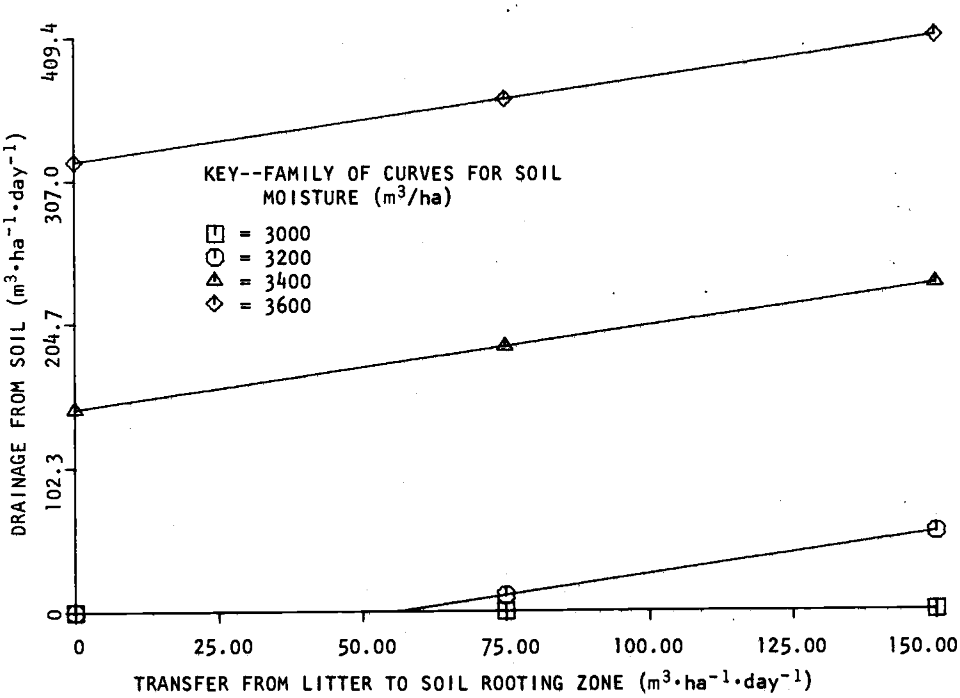
G_6--Potential evapotranspiration as a function of wind speed and energy input to canopy. Held constant: dew point temperature = 10°C, air temperature = 15°C.



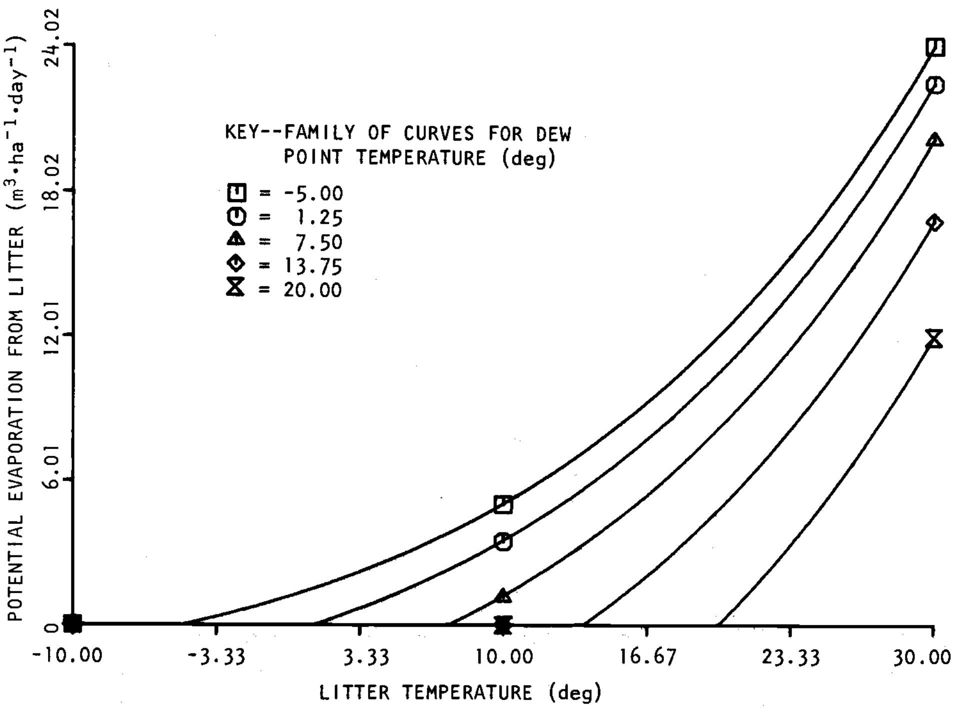
G_6--Potential evapotranspiration from canopy as a function of air and dew point temperatures. Held constant: energy input to canopy = 0.5 ly/min, daily precipitation = 100 m^3/ha, foliage biomass = 5 t/ha, wind speed = 1 m/sec.



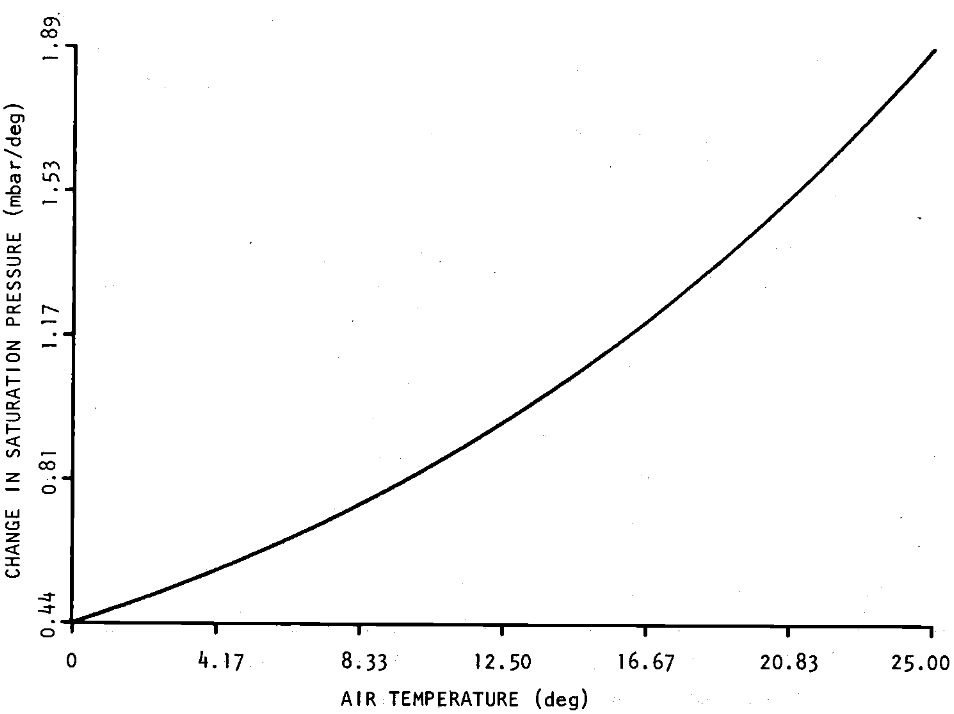
G_{12}--Drainage from soil rooting zone to subsoil as a function of drainage from litter to soil rooting zone and transpiration rate. Held constant: soil moisture = 3500 m^3/ha.



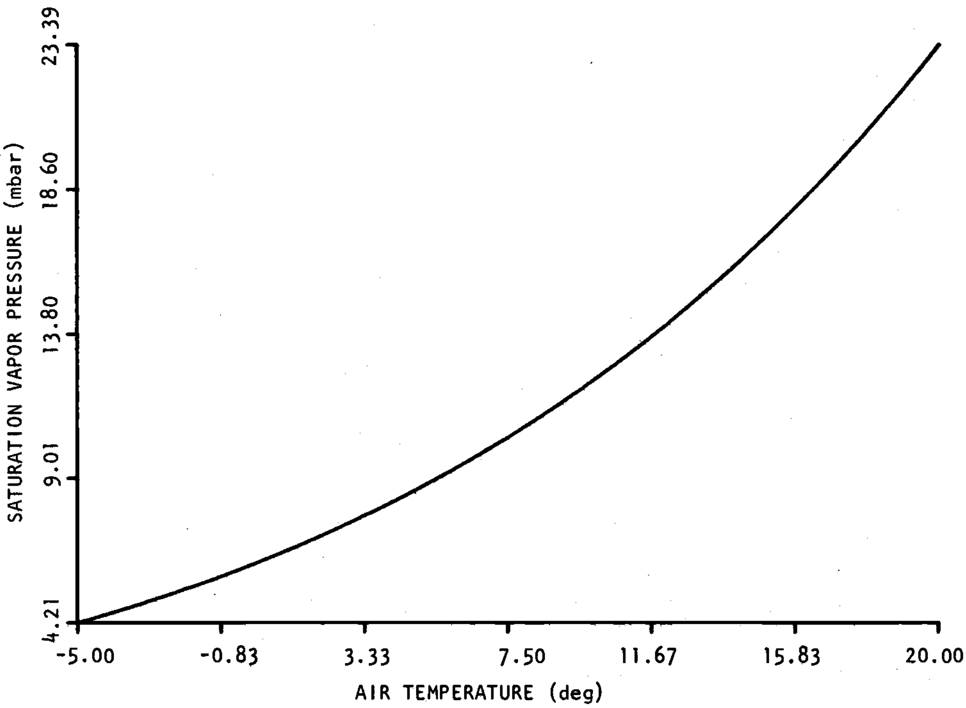
G_{12}--Drainage from soil rooting zone to subsoil as a function of drainage from litter to soil rooting zone and soil moisture.



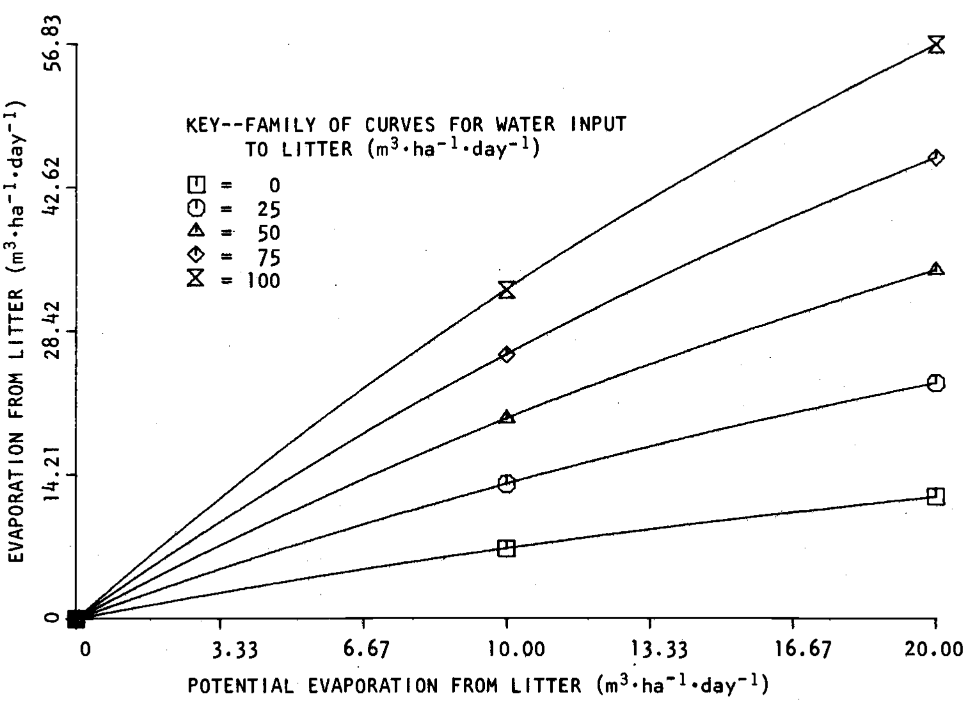
G_{14}--Potential evaporation from litter as a function of litter temperature and surface dew point temperature.



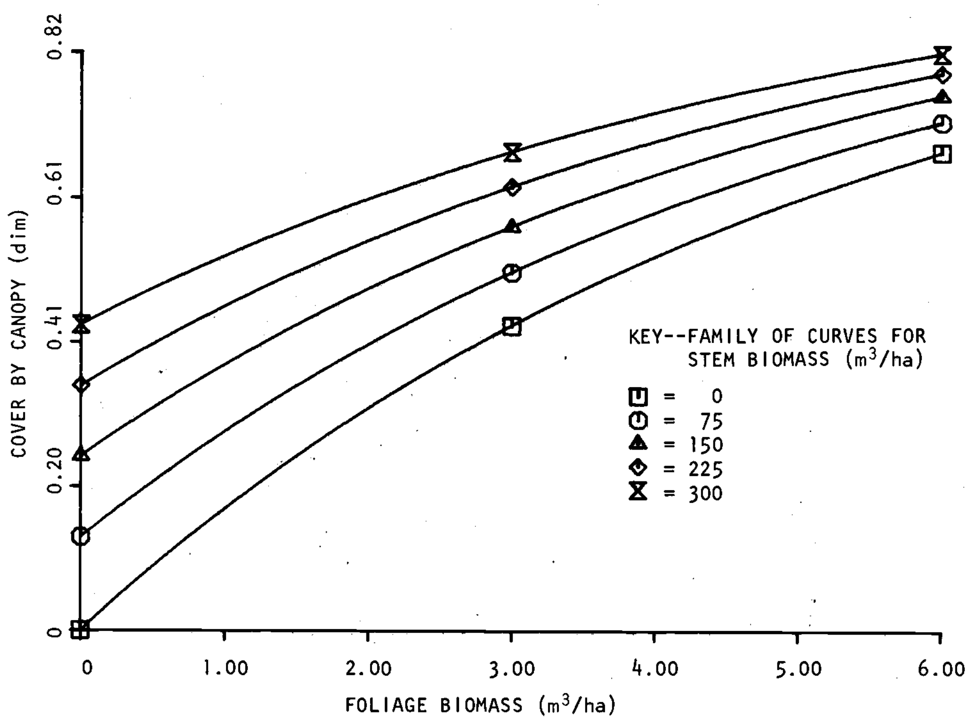
G_{17}--Rate of change of saturation vapor pressure as a function of air temperature.



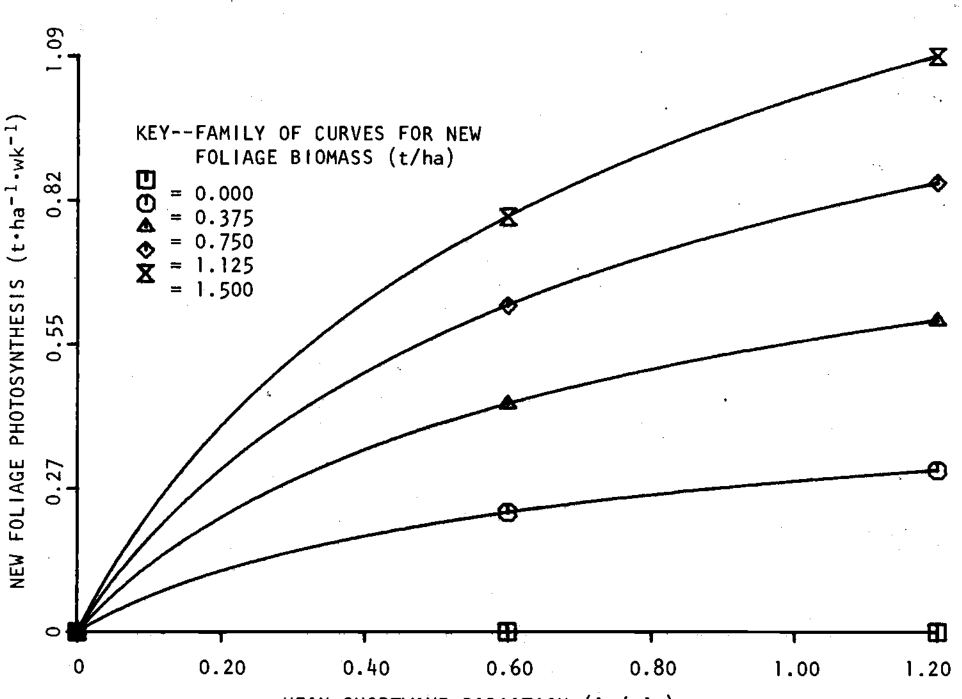
G_{21}--Saturation vapor pressure as a function of air temperature (Teten's equation).



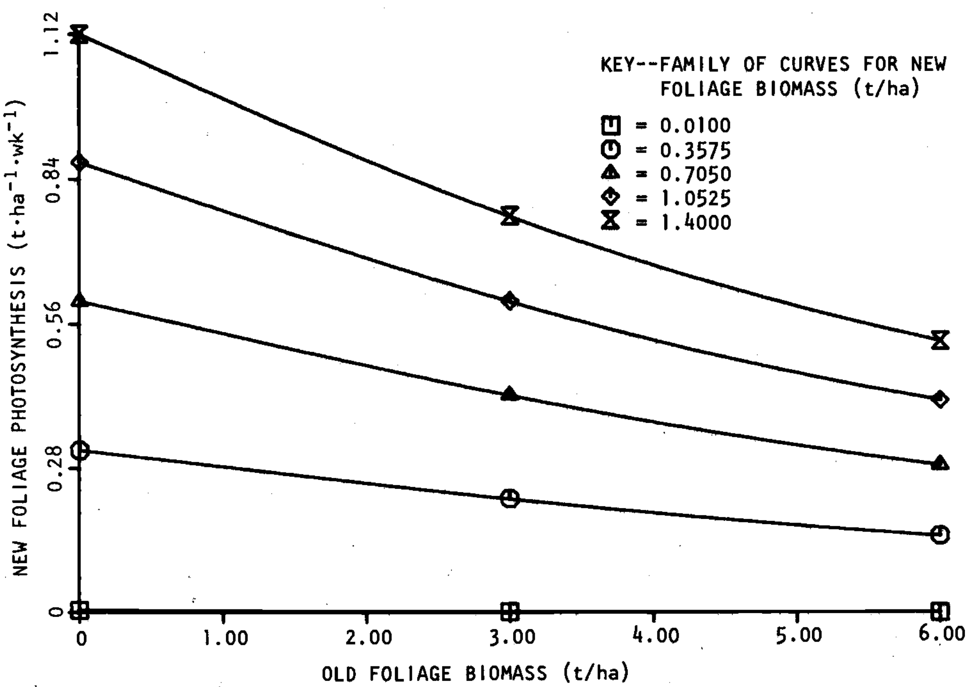
G_{22}--Evaporation from litter as a function of potential evaporation and water input to litter. Held constant: litter moisture-holding capacity = 129.7 m^3/ha, litter biomass = 39.5 t/ha, litter moisture = 40.0 m^3/ha.



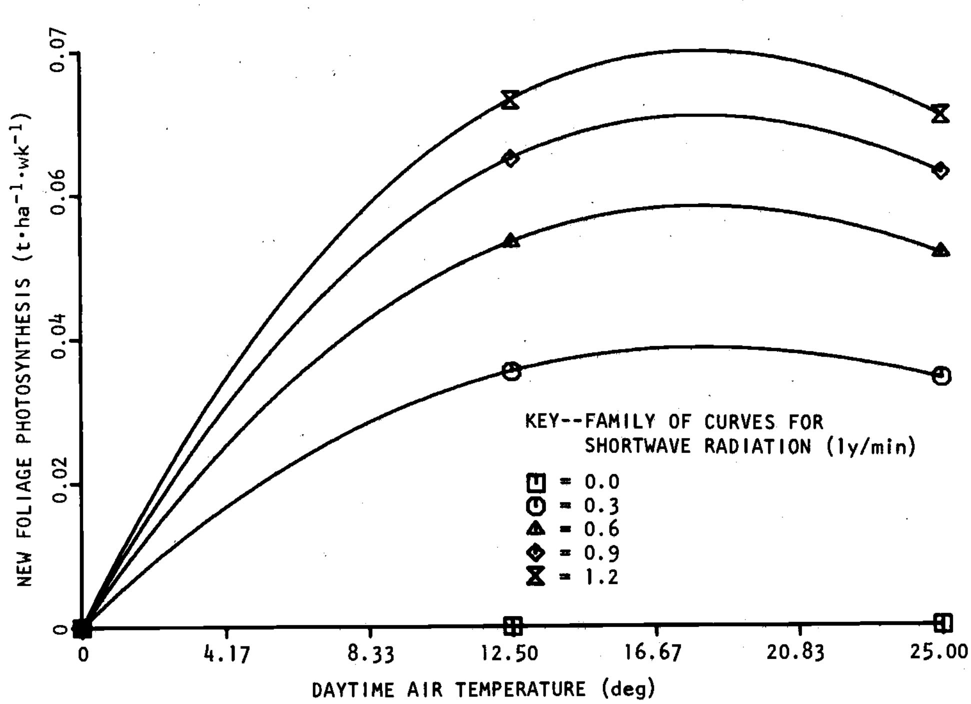
G_{23}--Fraction covered by canopy as a function of foliage biomass and stem biomass.



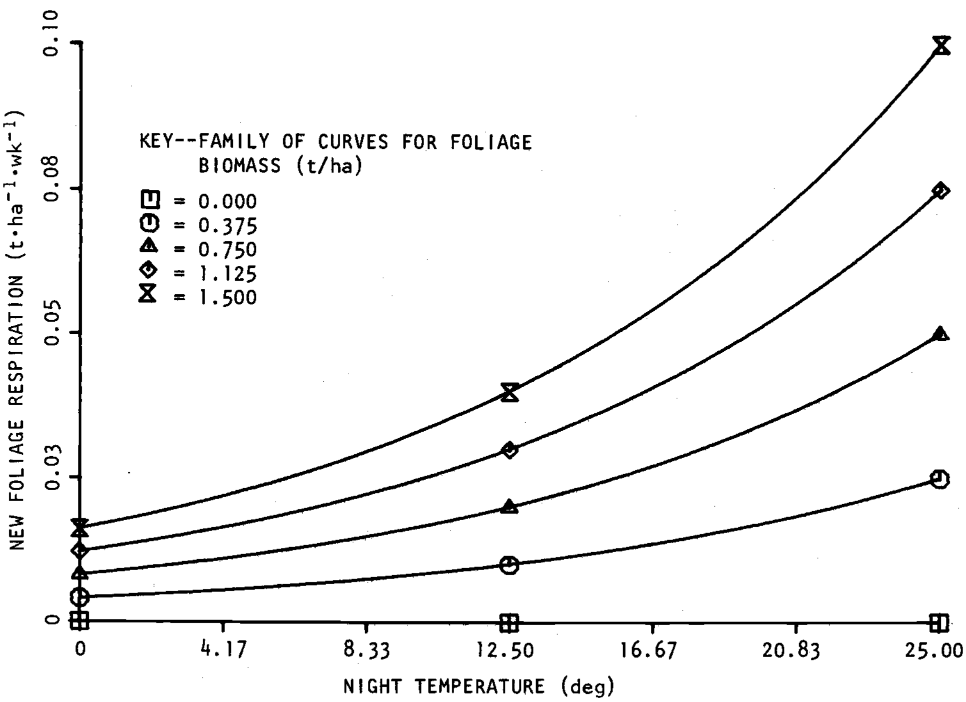
G_{24}--Photosynthesis by new foliage as a function of mean shortwave radiation input to canopy and new foliage biomass. Held constant: old foliage biomass = 4 t/ha, soil moisture = 3500 m^3/ha, air temperature = 15°C, day length = 0.5.



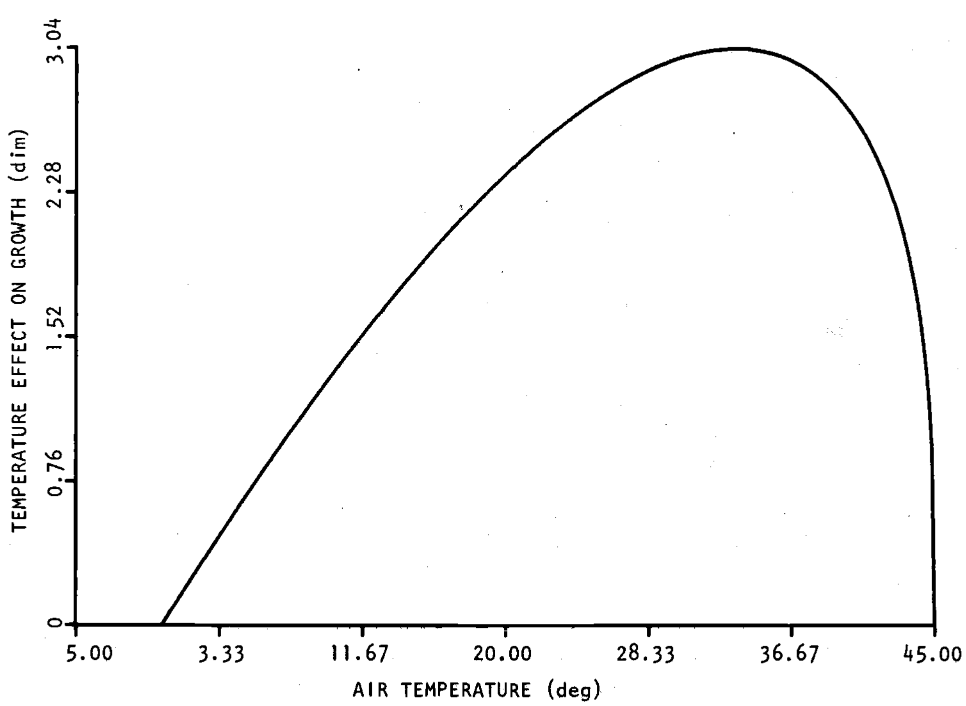
G_{24}--Photosynthesis by new foliage as a function of old foliage biomass and new foliage biomass. Held constant: mean light intensity = 0.5 ly/min, soil moisture = 3500 m^3/ha, air temperature = 15°C, day length = 0.5.



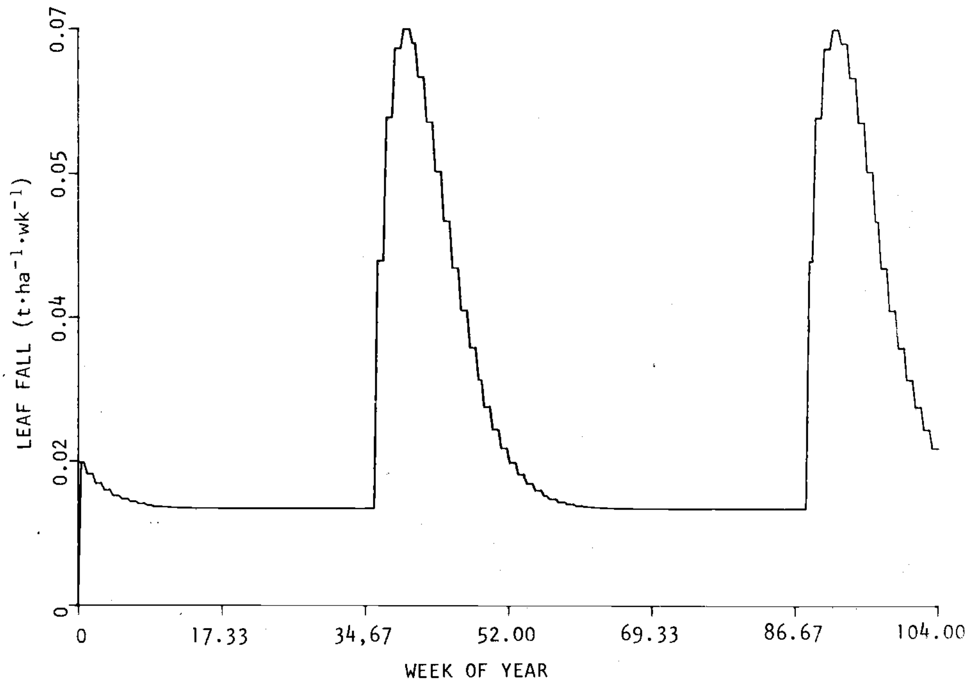
G_{24}--Photosynthesis by new foliage as a function of daytime air temperature and mean shortwave radiation input to canopy. Held constant: foliage biomass = 5.0 t/ha, soil moisture = 3500 m^3/ha, day length = 0.5.



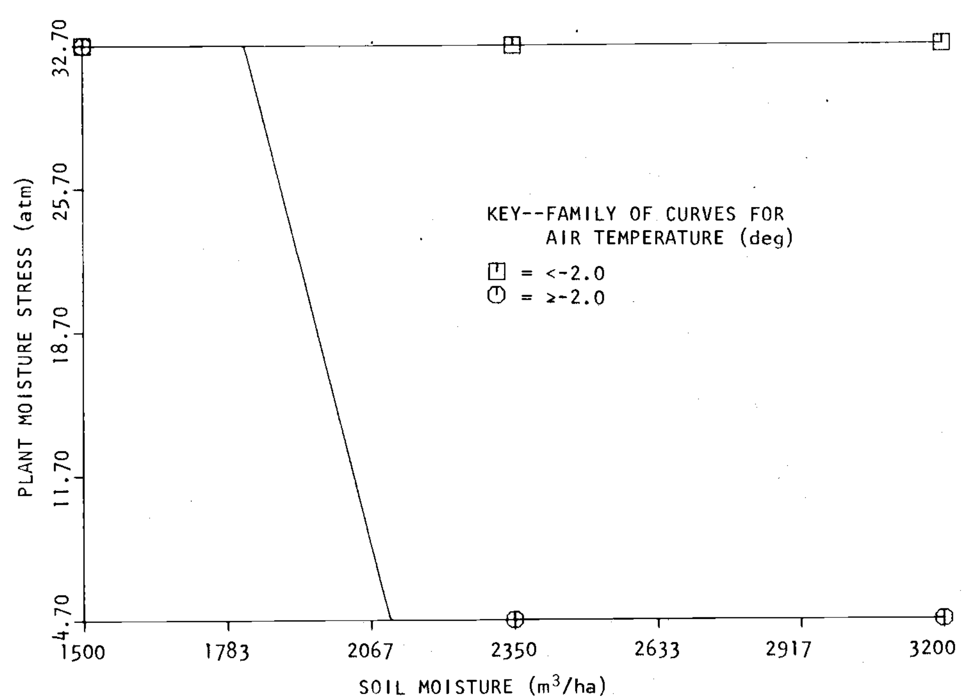
G$_{25}$--New foliage respiration as a function of nighttime temperature and new foliage biomass. Held constant: day length = 0.5.



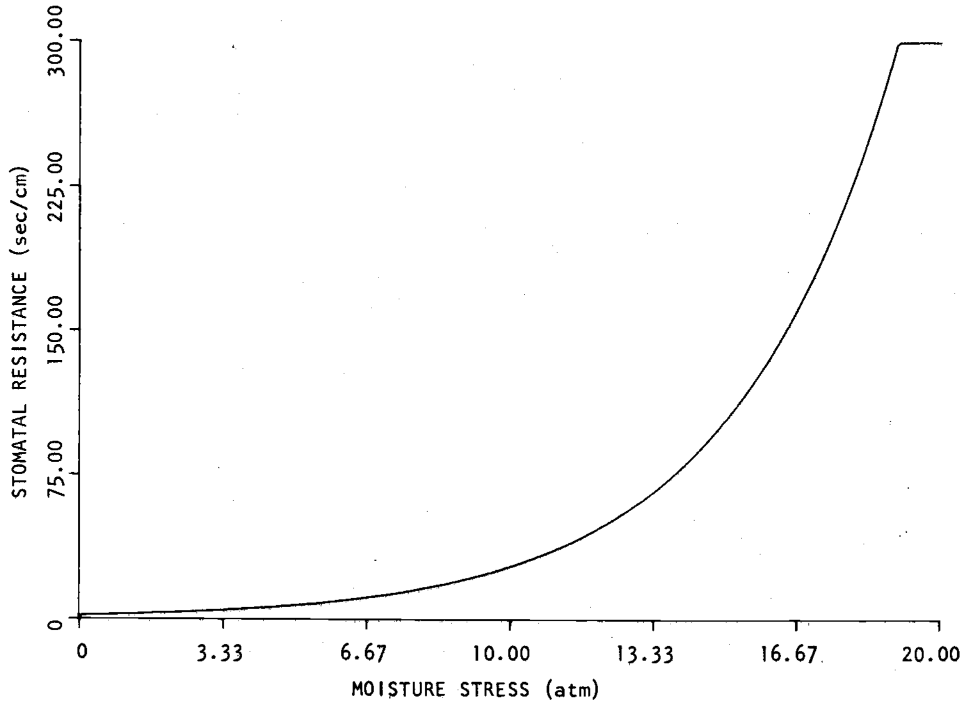
G$_{39}$--Effect of air temperature on various growth processes.



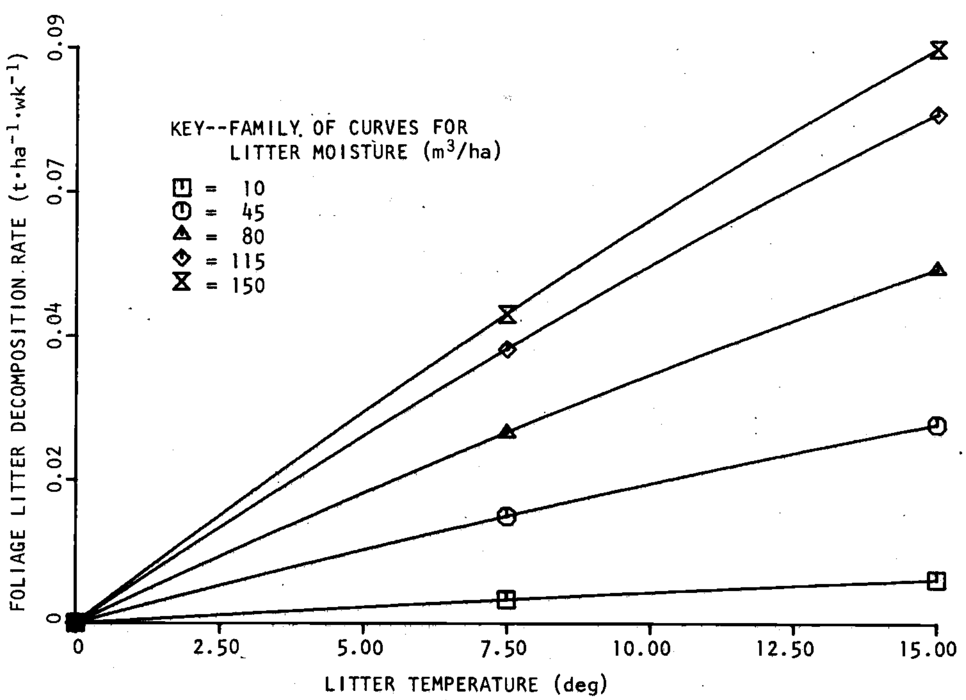
G_{40}--Leaf fall pattern. Held constant: old foliage biomass = 4 t/ha.



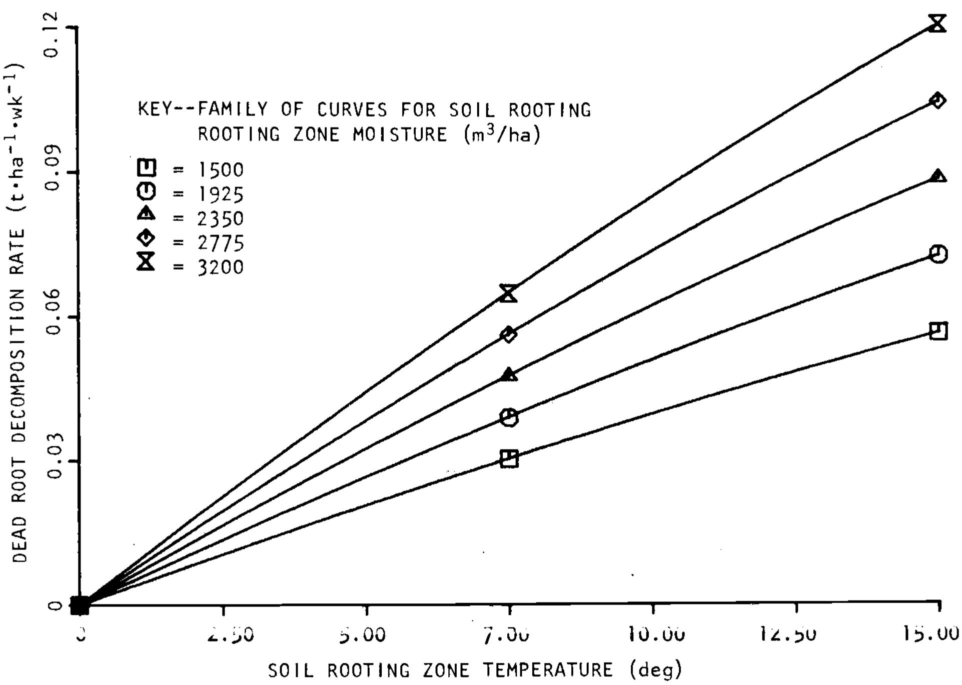
G_{42}--Predawn plant moisture stress as a function of soil moisture and air temperature.



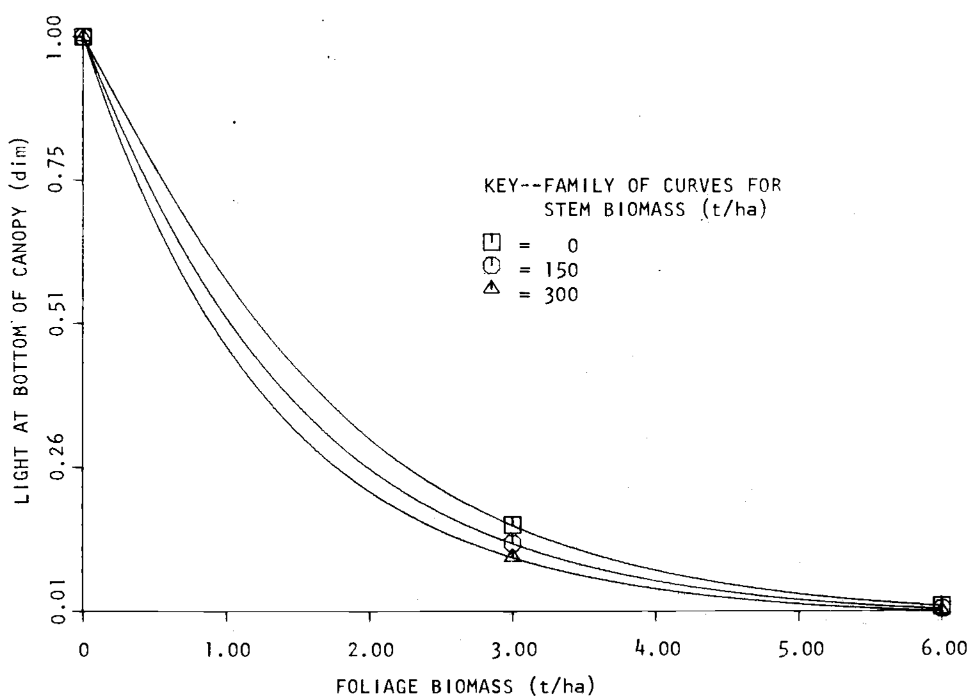
G_{43}--New foliage stomatal resistance as a function of predawn plant moisture stress.



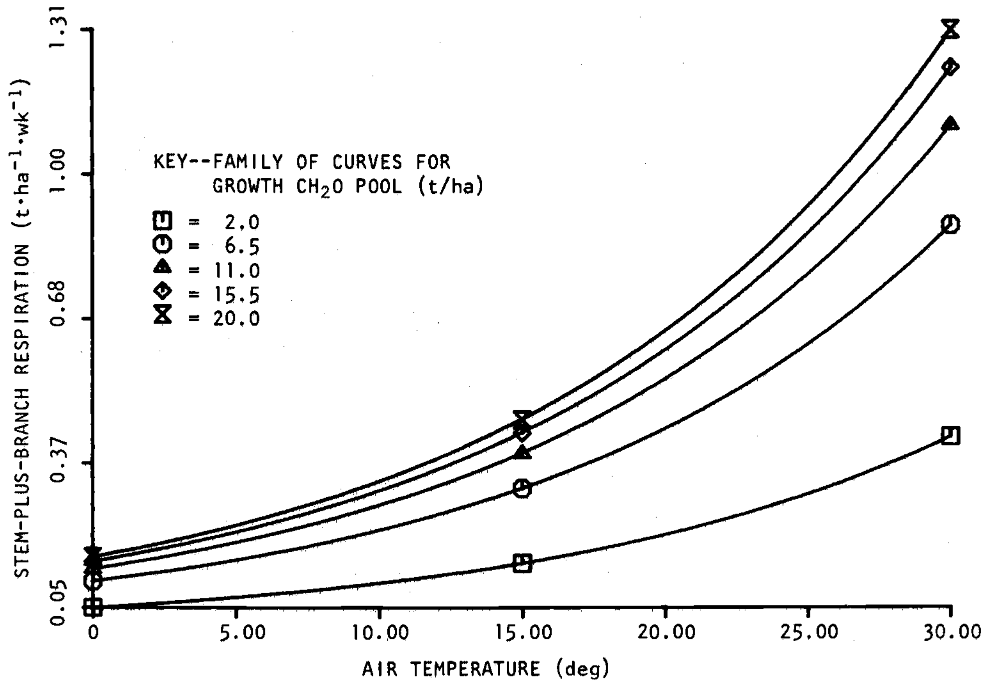
G_{81}--Foliage litter decomposition rate as a function of litter temperature and litter moisture. Held constant: litter biomass = 39.5 t/ha.



G_{85}--Dead root decomposition rate as a function of soil rooting zone temperature and soil rooting zone moisture. Held constant: dead root carbon = 6.197 t/ha.



G_{91}--Light penetration to bottom of canopy as a function of foliage biomass and stem biomass. Light penetration is expressed as a fraction of light at top of canopy.



G_{138}--Stem-plus-branch respiration as a function of air temperature and growth carbohydrate pool size.

6.3. *Tree Diagrams*

In this section we present a sequence of tree diagrams detailing the interrelationships between all variables in the model. The calculation of *G*'s in the code is segmented into 18 modules. The *G*'s in modules 1-8 are calculated daily; those in the remaining modules are calculated weekly. Each page of the tree diagrams refers to a module in the code.

In general, a dashed line indicates flow of information into or out of a module while a solid line indicates information flow within the module. Information flow (calculation) proceeds generally from top to bottom. (Module 5 contains two instances in which complex topology of the tree forced us to draw two lines that lead downward, but bend upward at the bottom.) A solid circle (●) indicates a junction; all variables from which lines lead downward to the junction are used in calculating all variables to which lines lead downward from the junction.

The *G*'s can depend on values of state variables (*X*'s), driving variables (*Z*'s), and other *G* variables, as well as referring to special (*S*) functions, and we have used a pictorial system of distinguishing among the variable types. The *G*'s are indicated by circles with the index written inside. A dashed-line circle indicates that the *G* was calculated in an earlier module. The *Z*'s are indicated by solid-line triangles and *X*'s by solid-line squares. When *S* functions are used in calculating a *G*, the *S* is indicated by a dashed-line rectangle with the arguments of the function shown leading into it from above. Each time a *G* corresponding to a flow is calculated, we show it with a dashed line leading to the right. At the extreme right-hand margin, at the end of these dashed lines, we have written the corresponding flow term.

The diagrammatic conventions used in the tree diagrams are summarized below:

□ state variable (*X*)

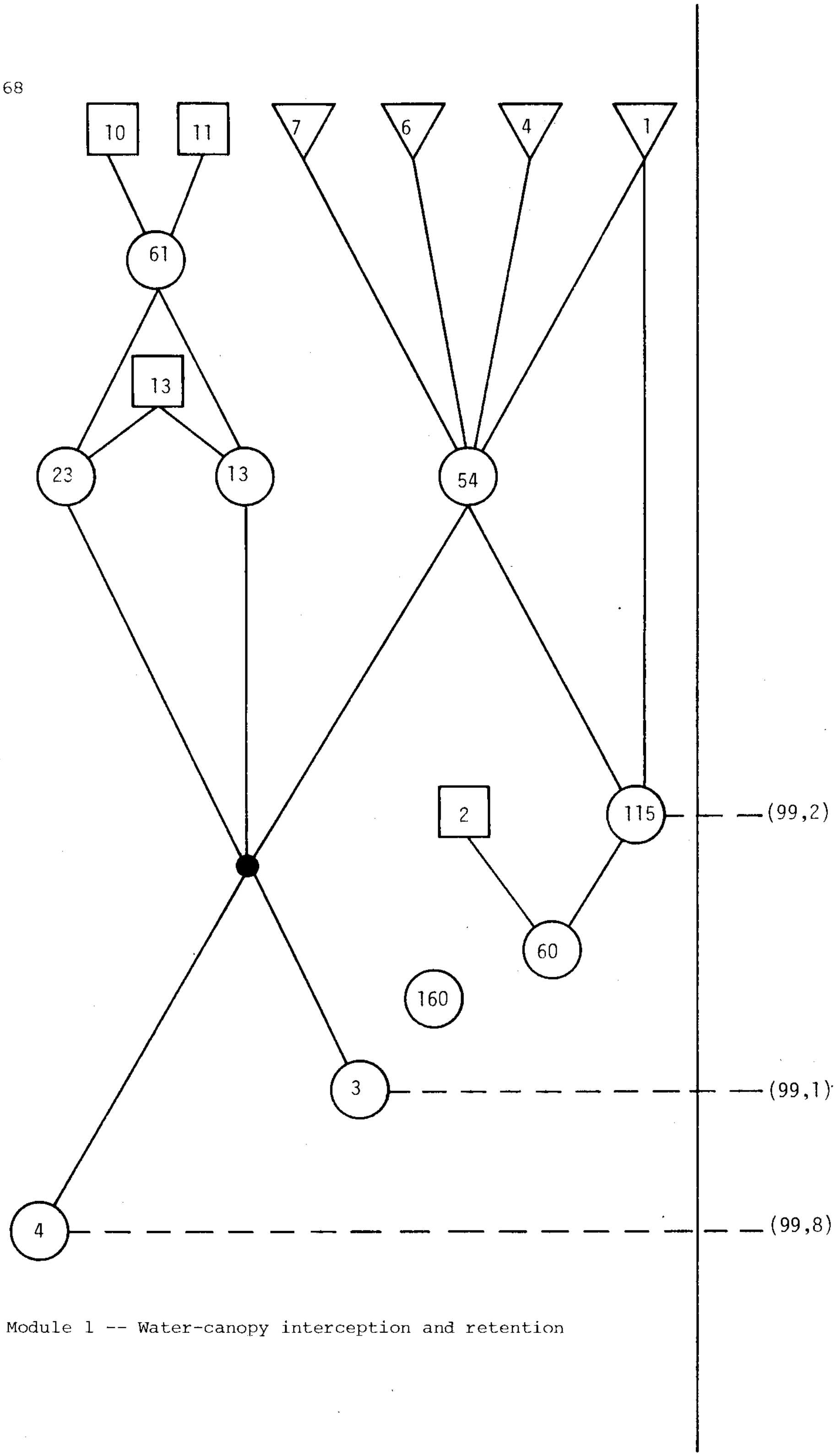
▽ driving variable (*Z*)

○ intermediate variable (*G*) calculated in the module

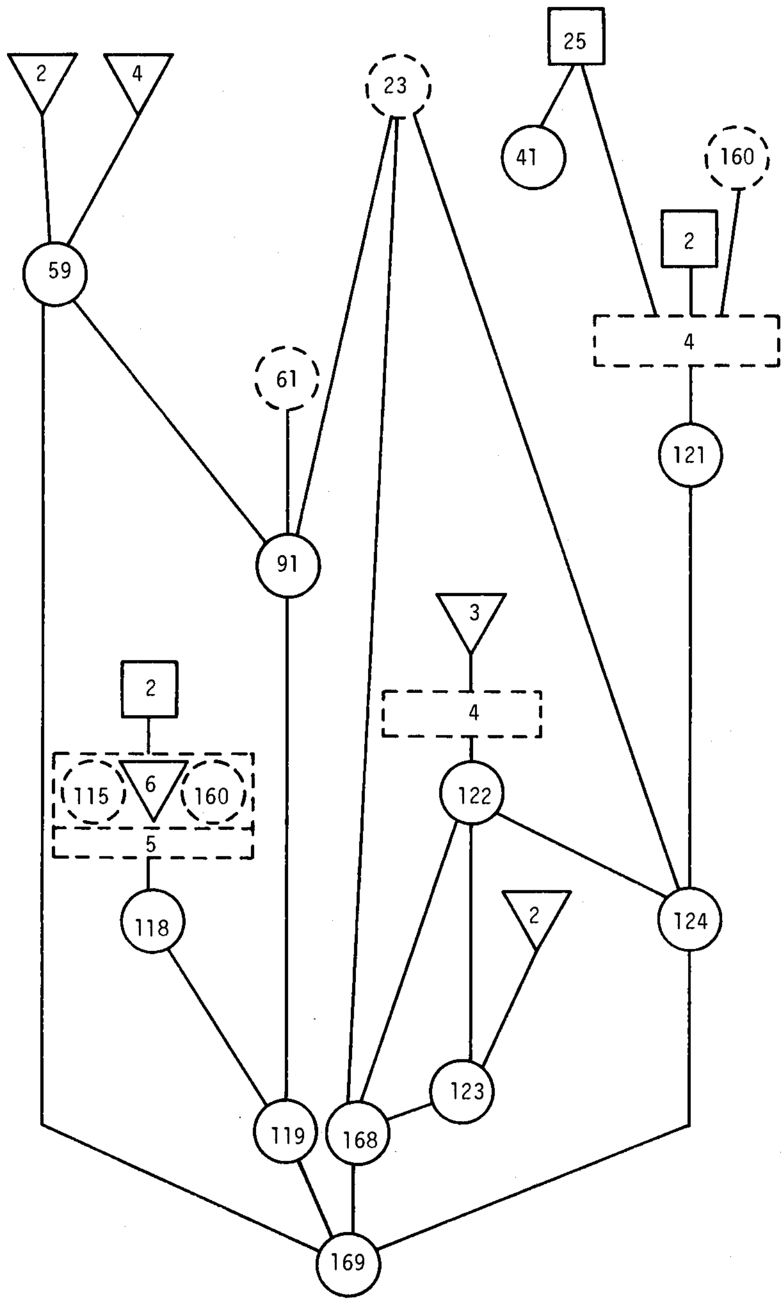
◌ intermediate variable (*G*) calculated in previous module

⬚ special function (*S*)

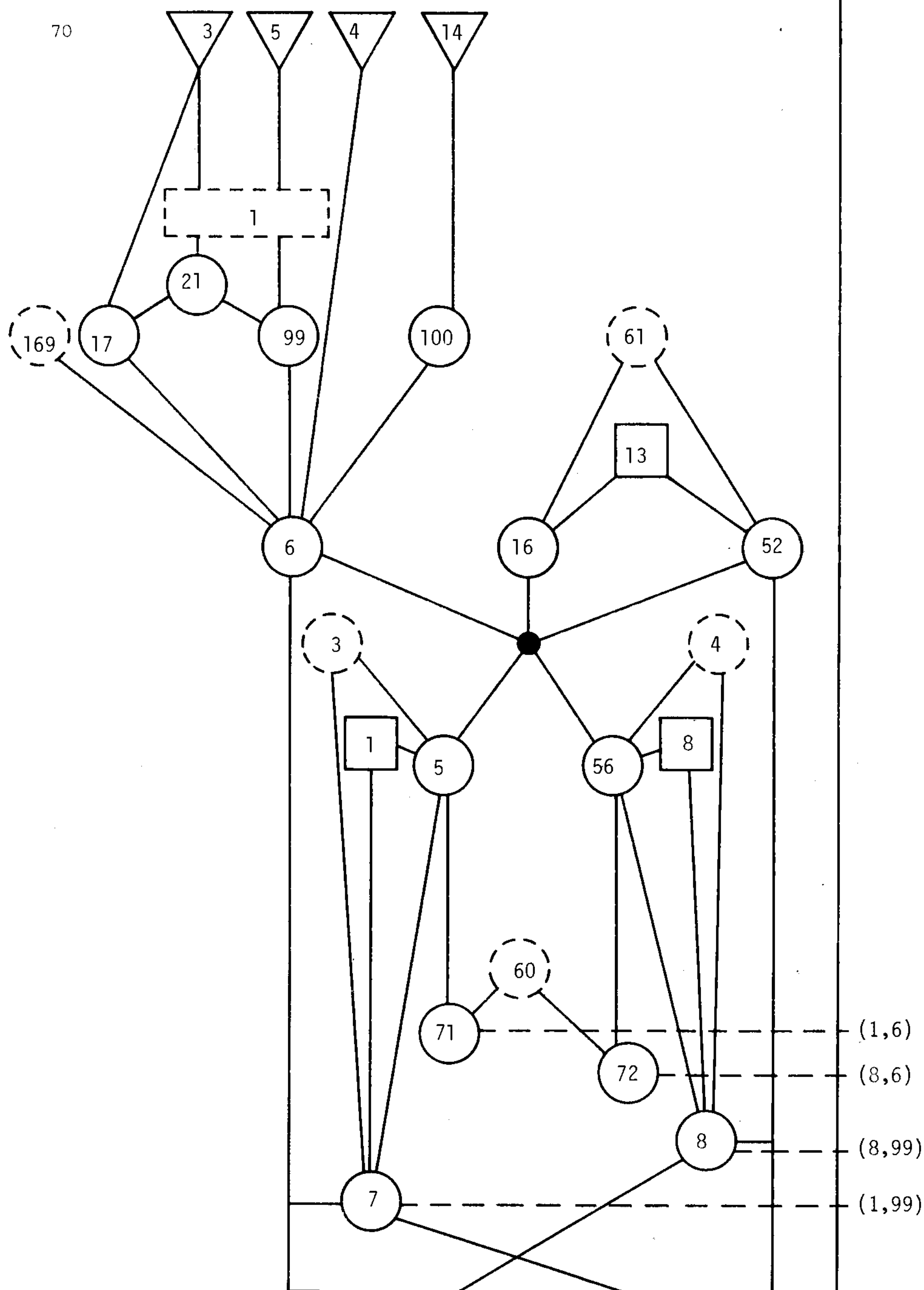
● junction



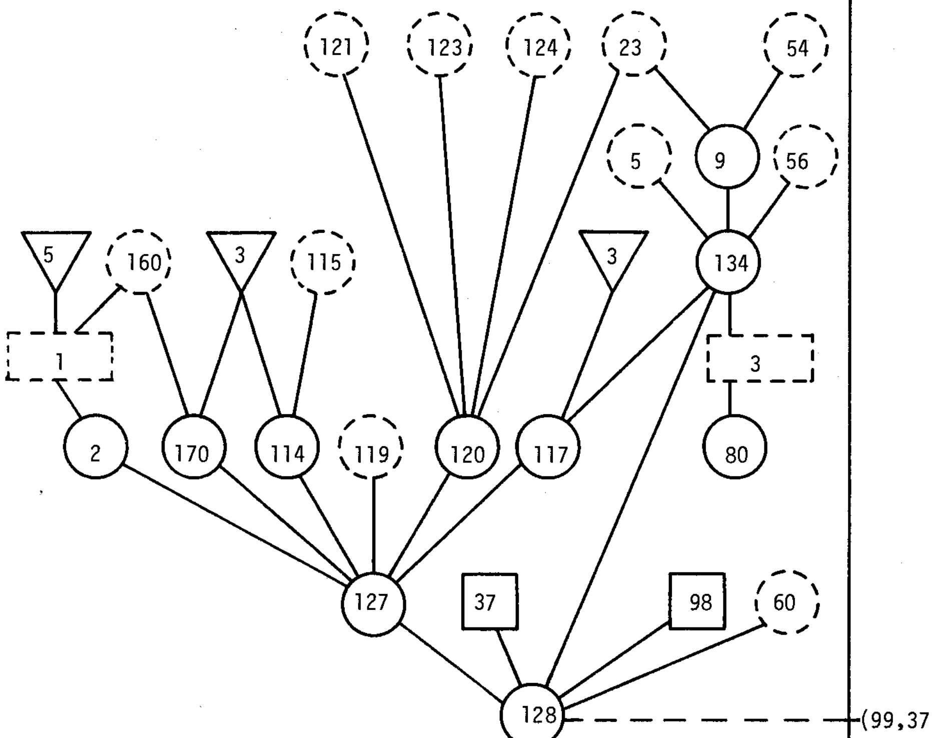
Module 1 -- Water-canopy interception and retention



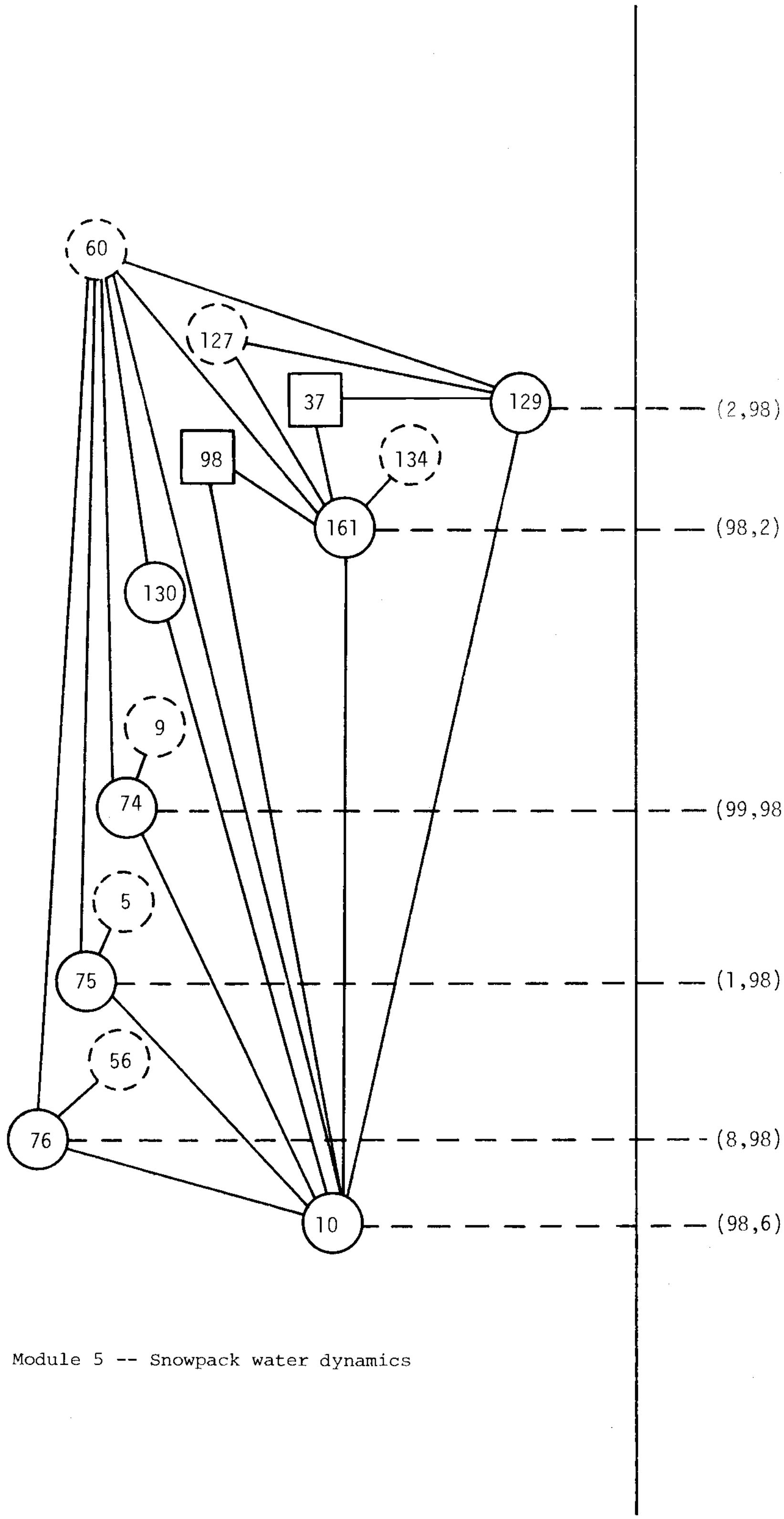
Module 2 -- Canopy energy balance



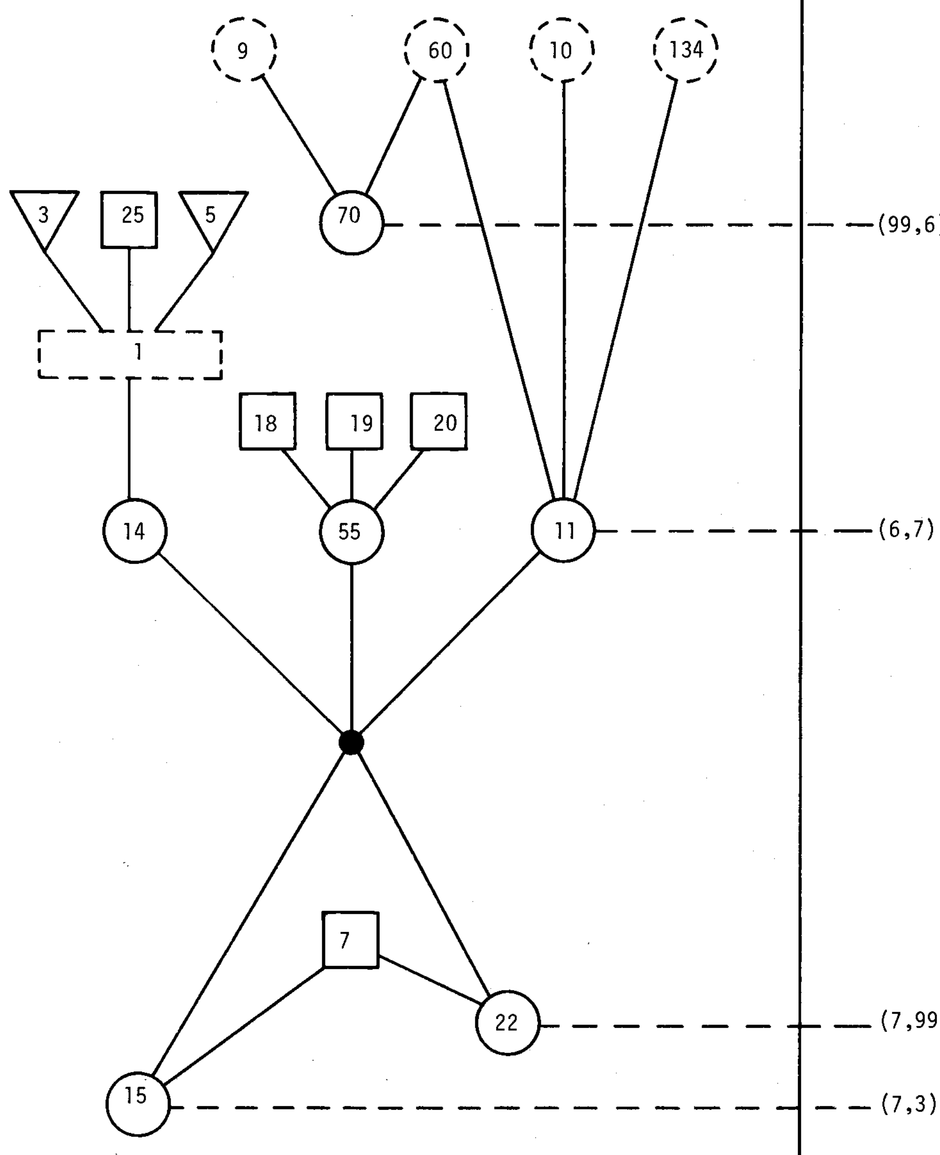
Module 3 -- Water-canopy evaporation and drip



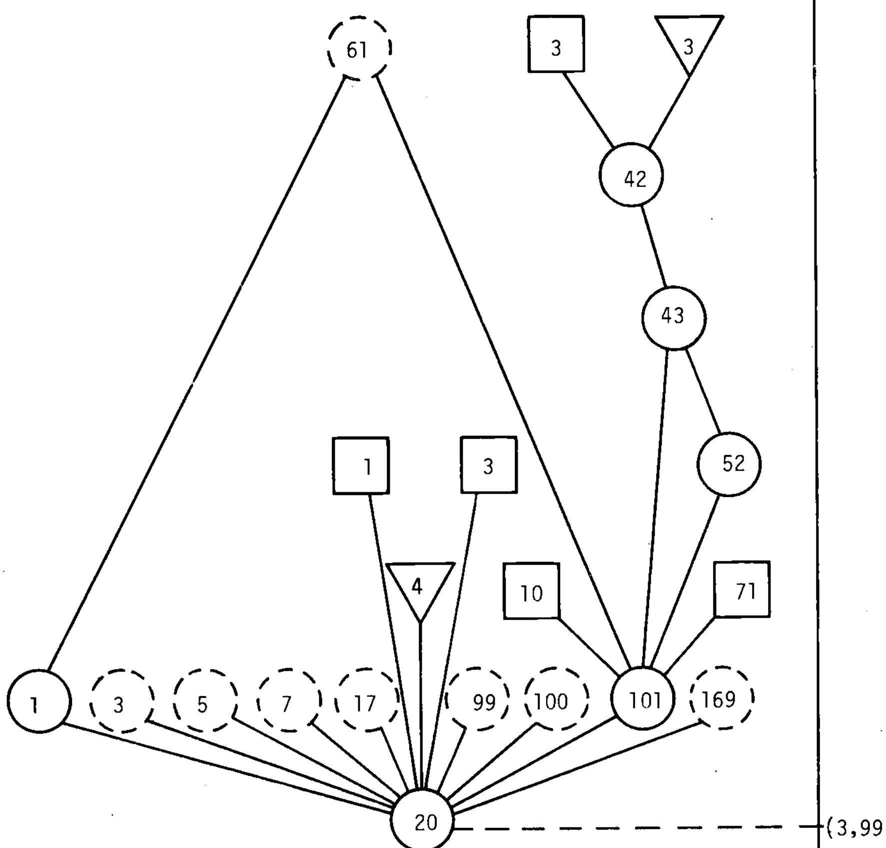
Module 4 -- Snowpack energy balance



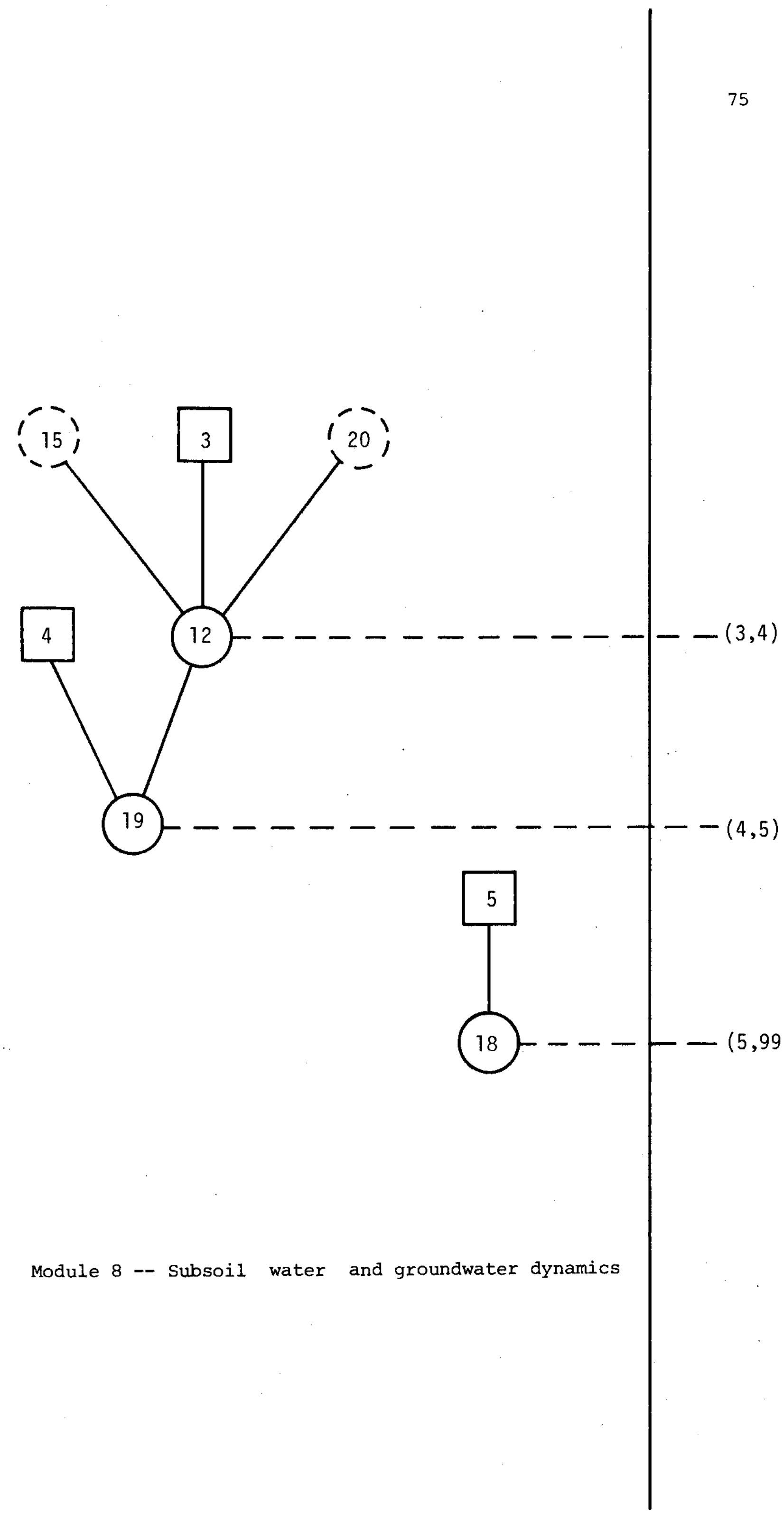
Module 5 -- Snowpack water dynamics



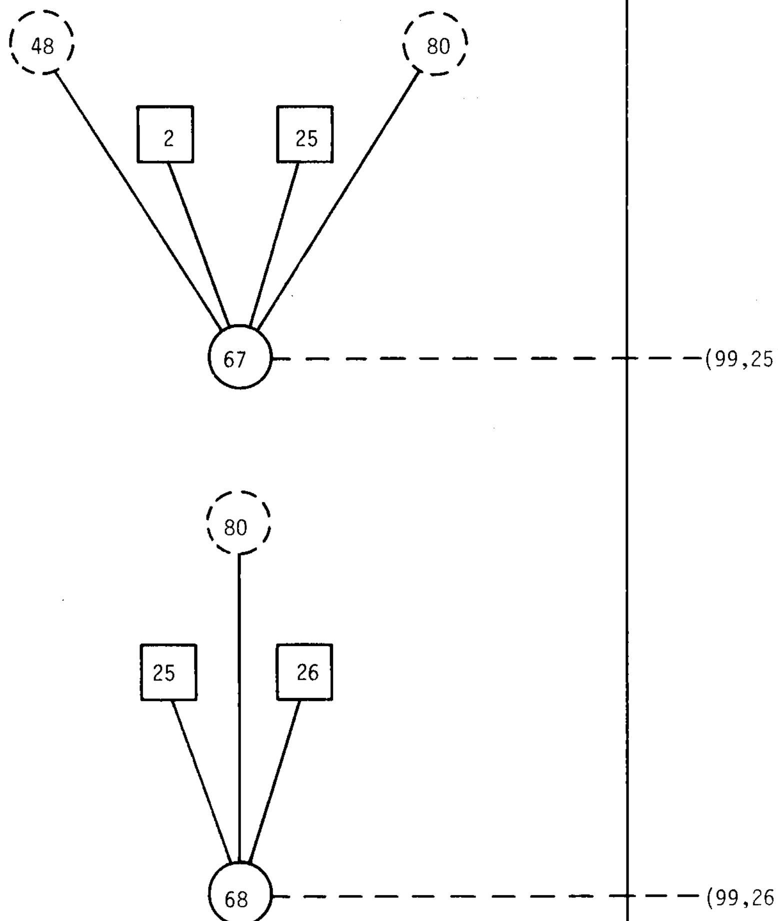
Module 6 -- Litter water dynamics



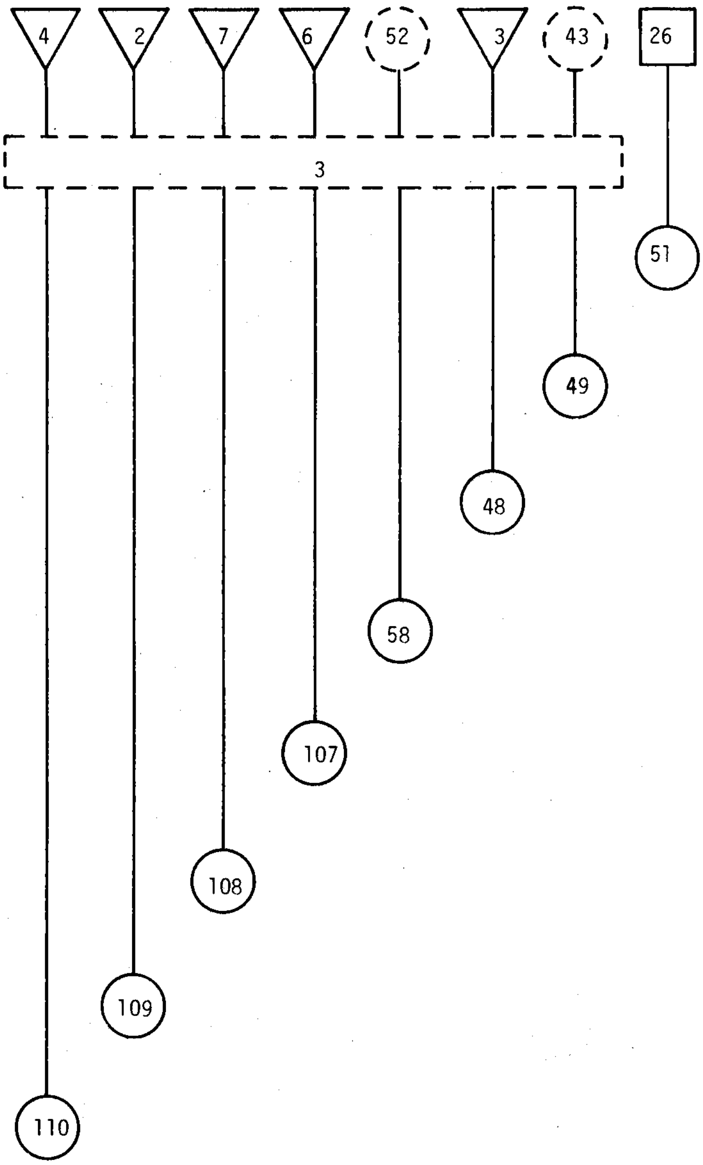
Module 7 -- Transpiration



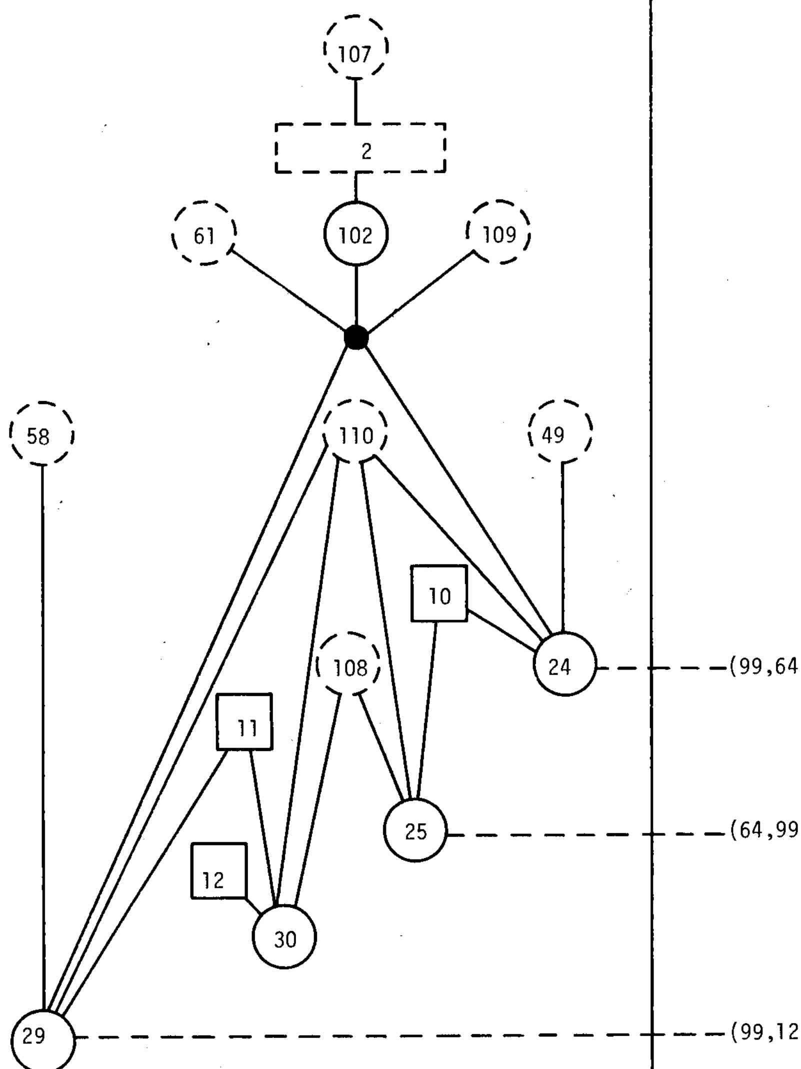
Module 8 -- Subsoil water and groundwater dynamics



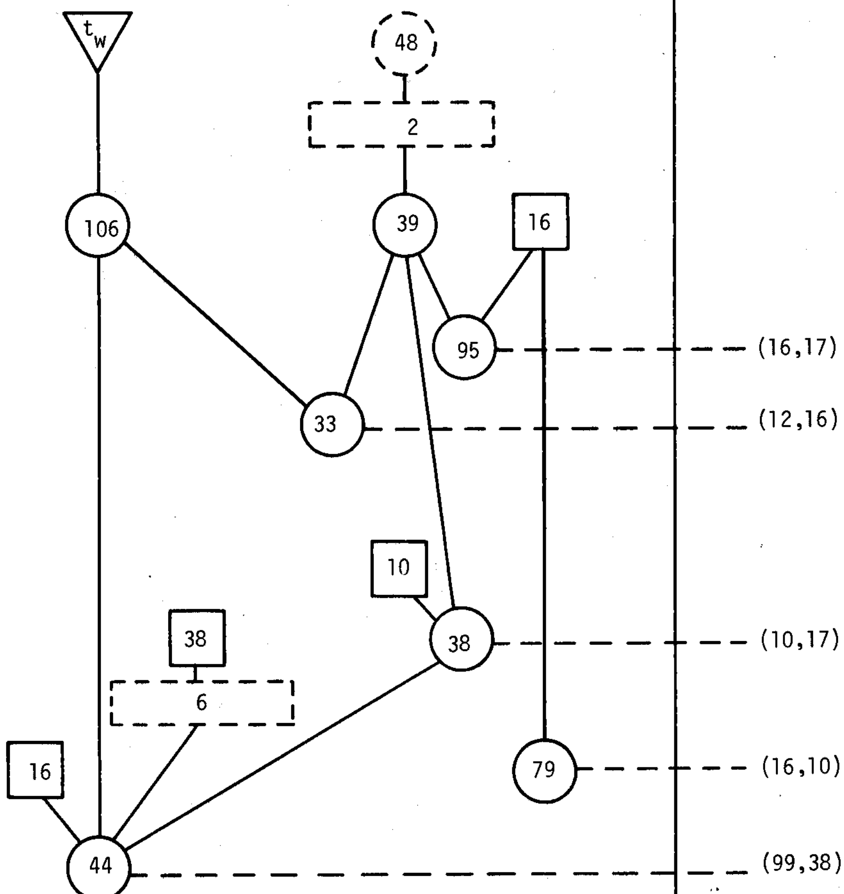
Module 9 -- Litter and soil temperature



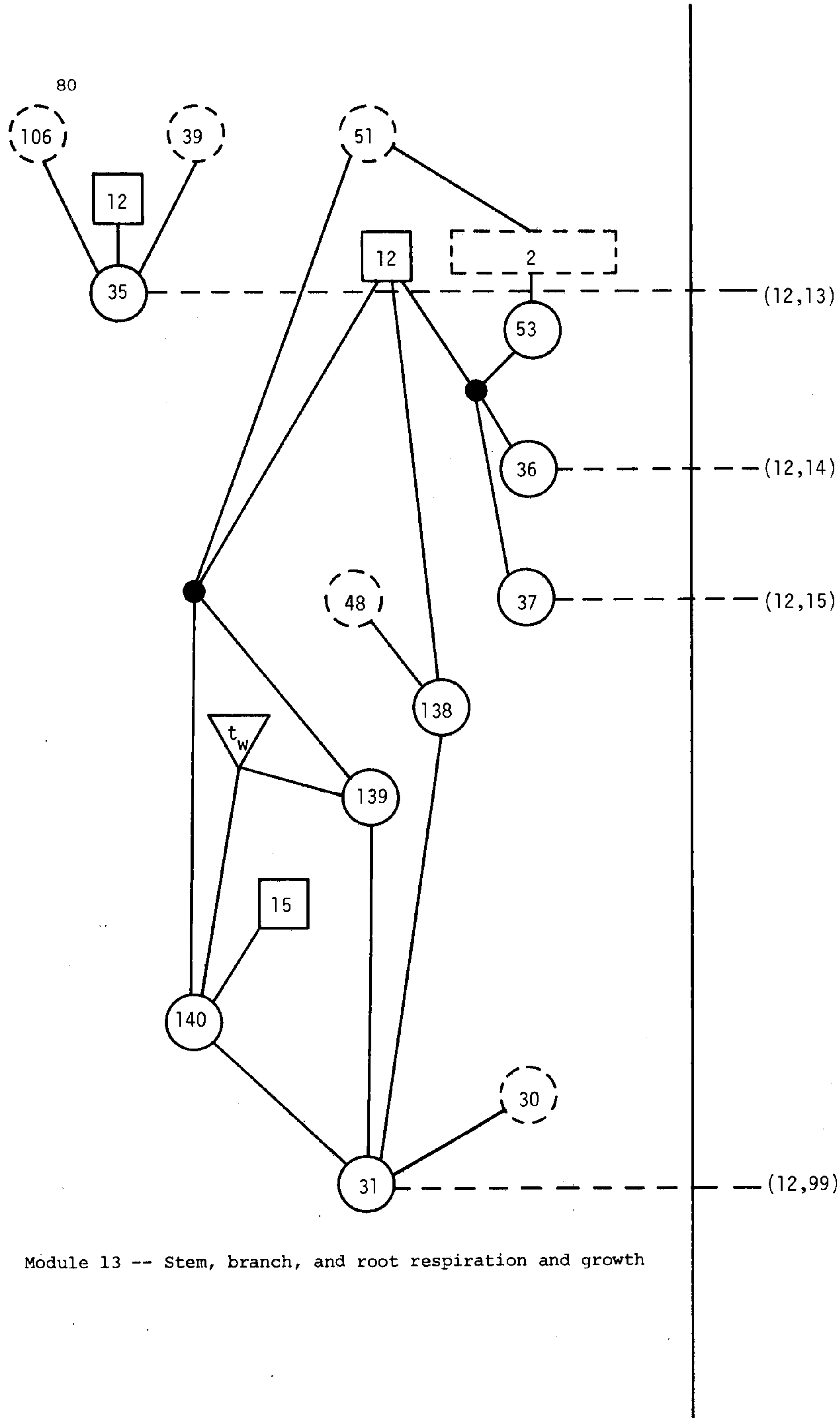
Module 10 -- Weekly averages



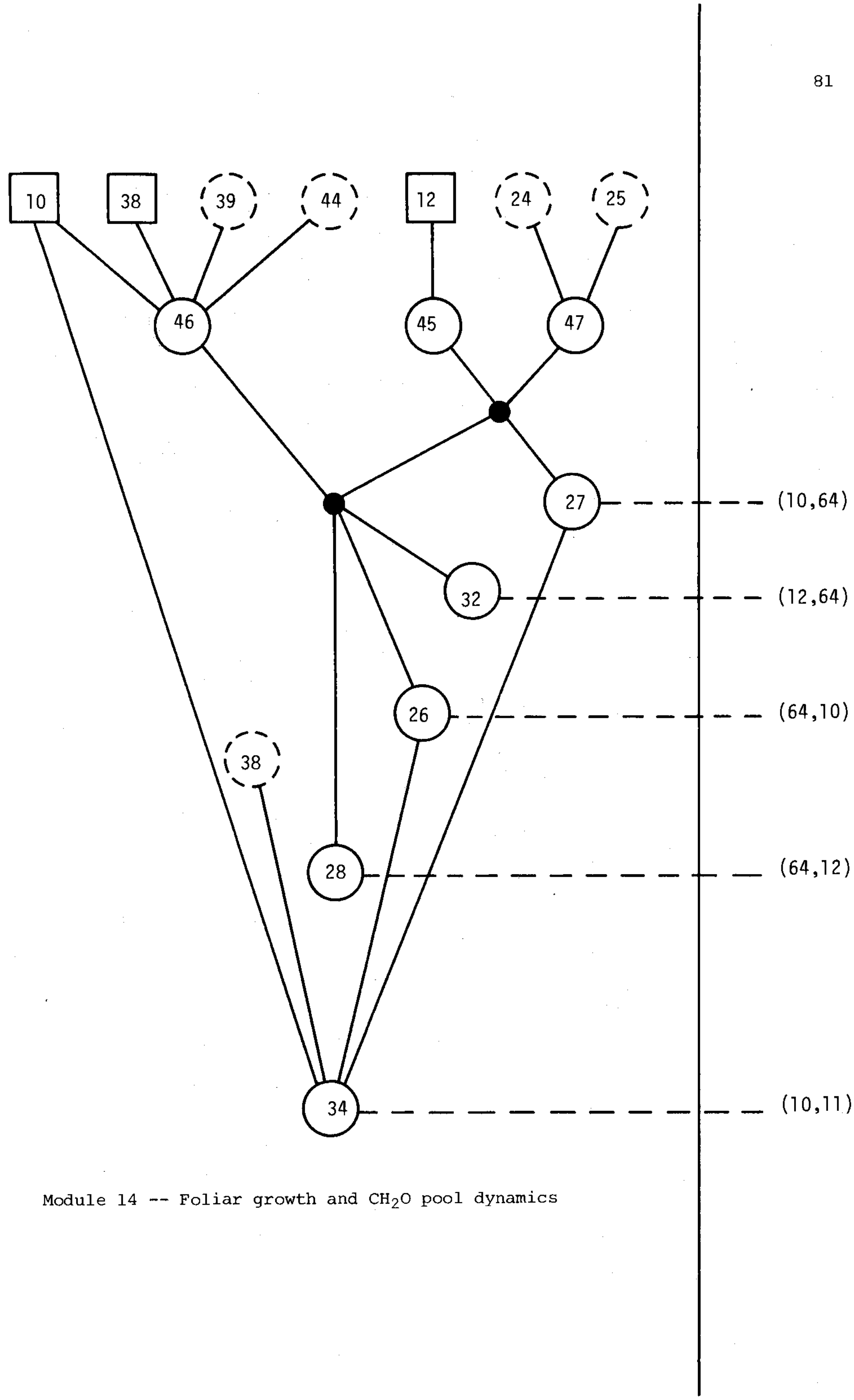
Module 11 -- Photosynthesis and foliar respiration



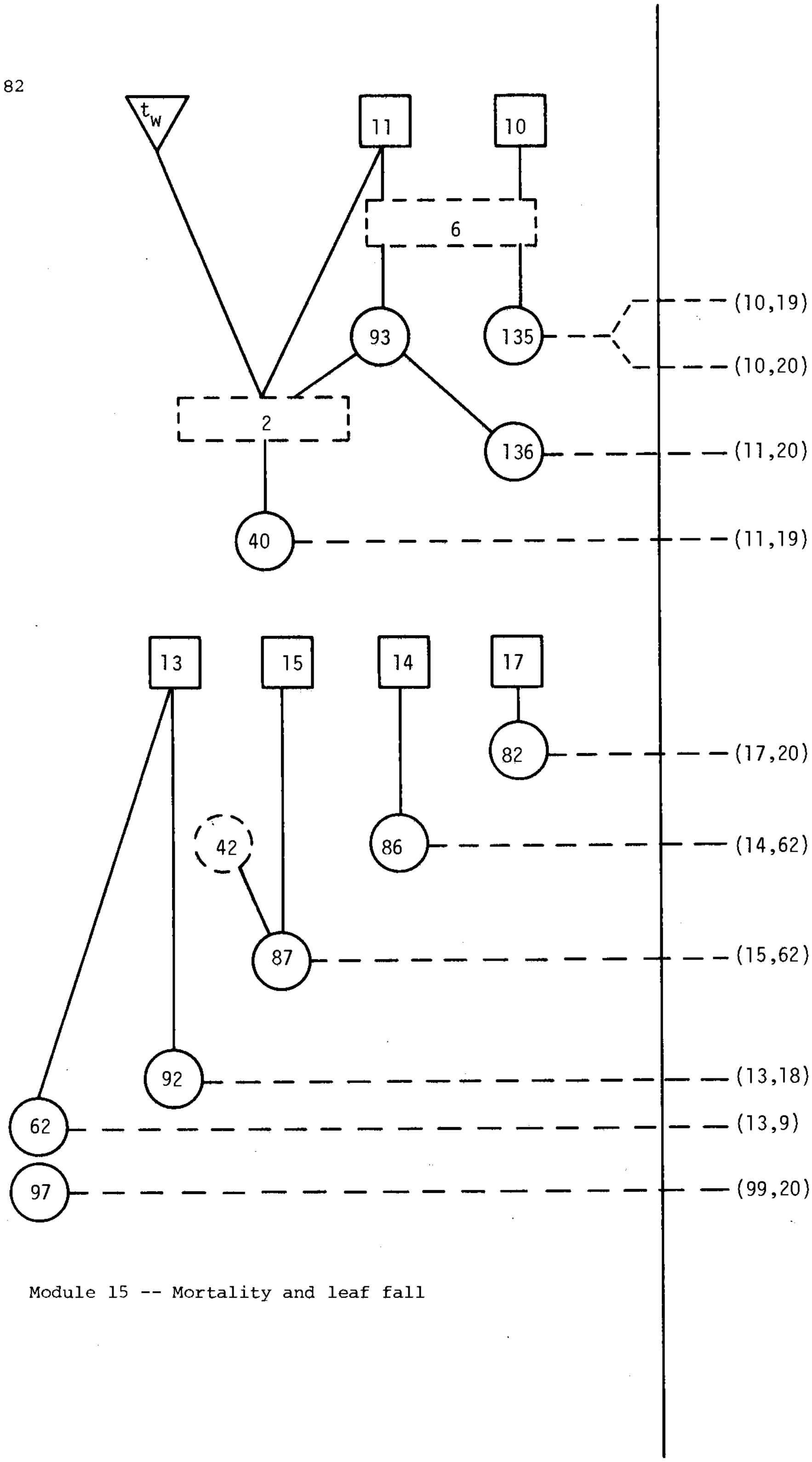
Module 12 -- Bud dynamics and foliar growth limits



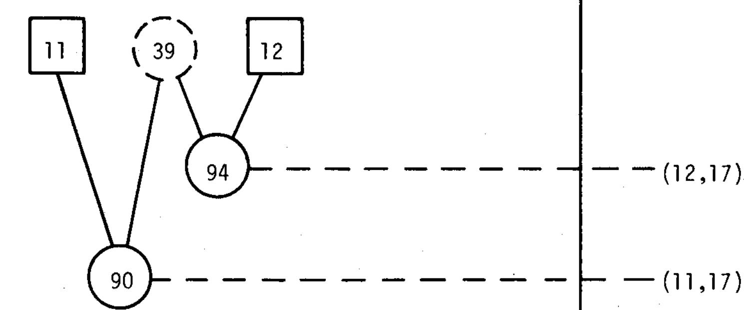
Module 13 -- Stem, branch, and root respiration and growth



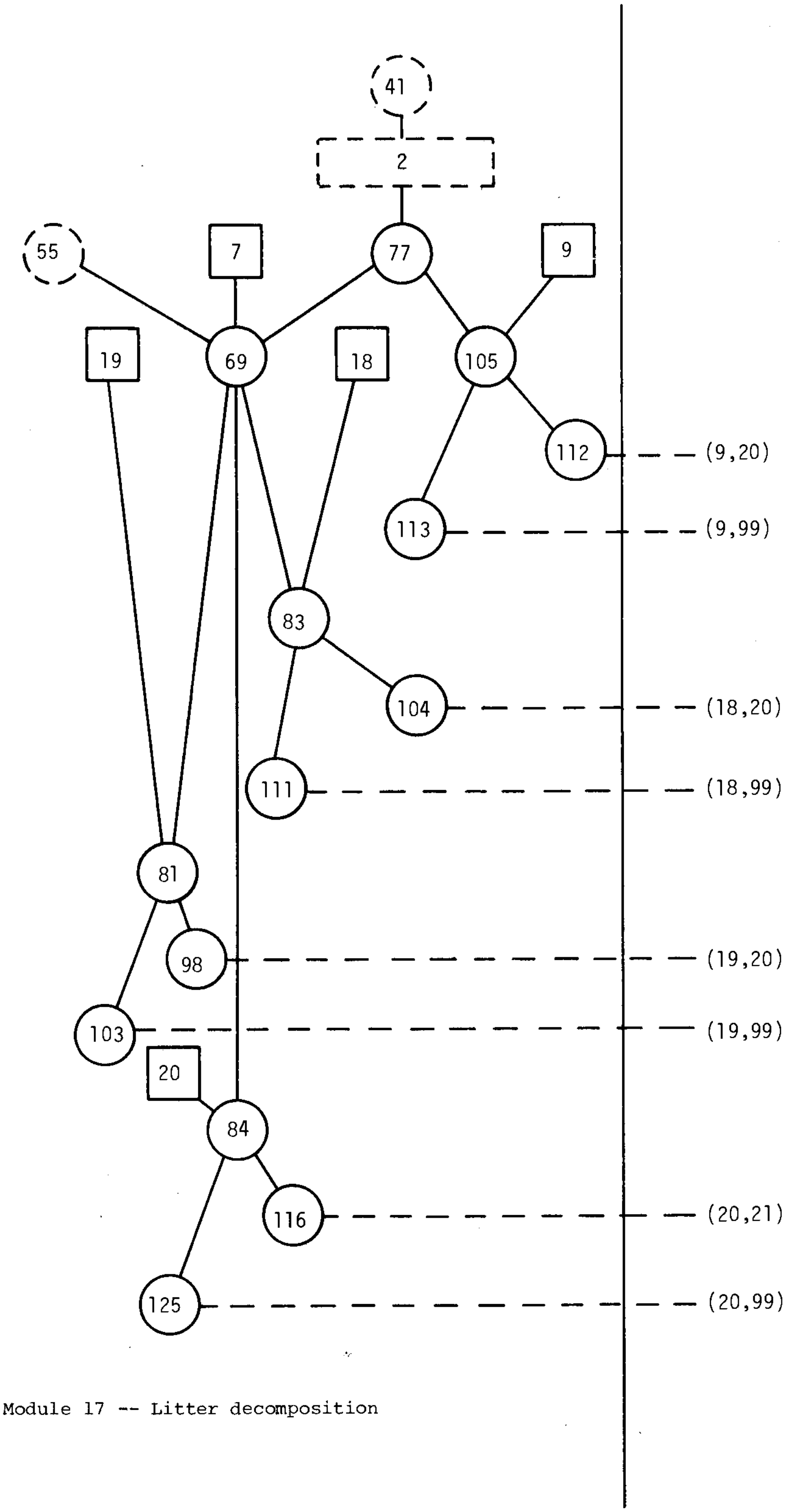
Module 14 -- Foliar growth and CH_2O pool dynamics



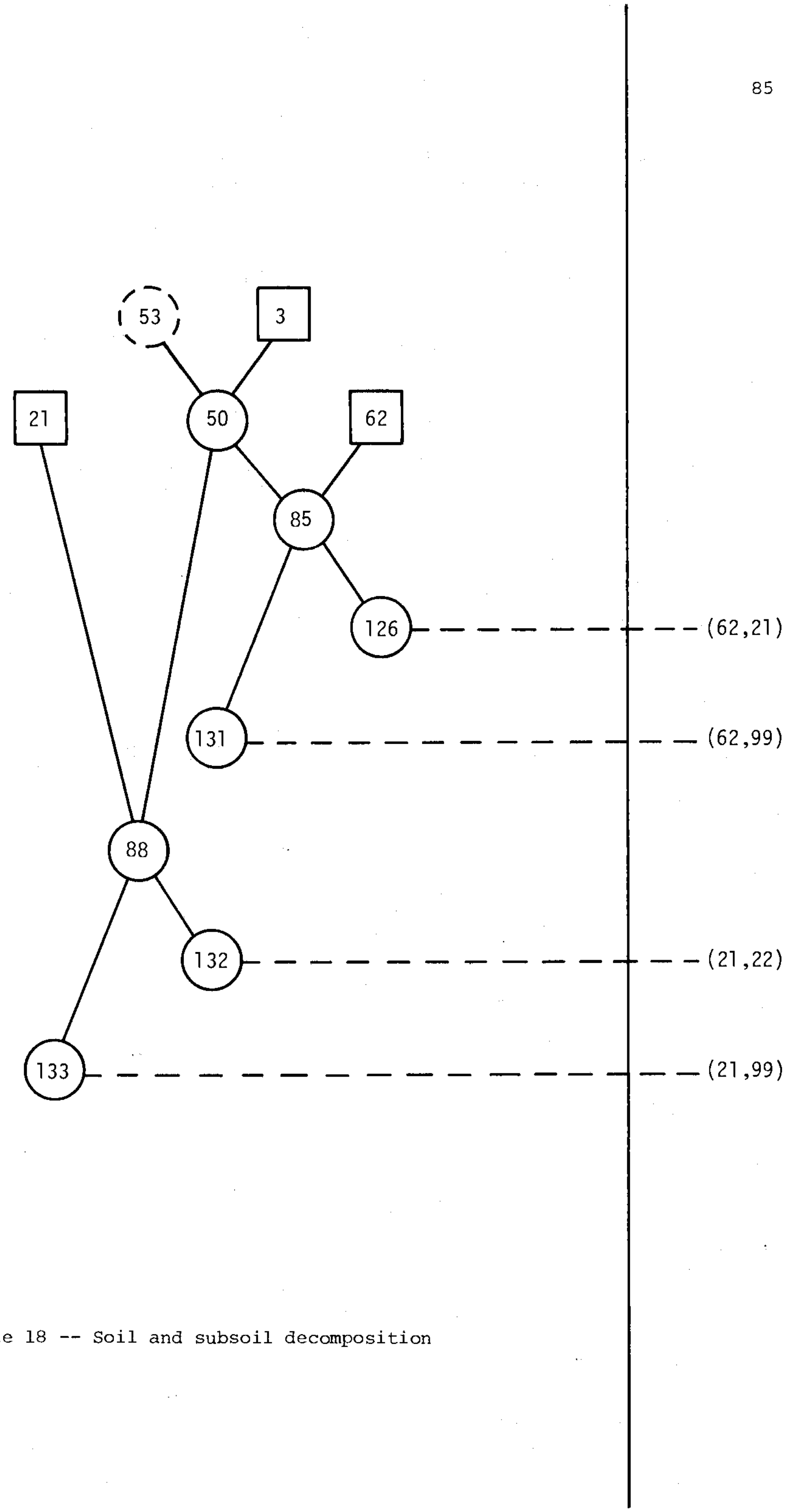
Module 15 -- Mortality and leaf fall



Module 16 -- Old foliage consumption



Module 17 -- Litter decomposition



Module 18 -- Soil and subsoil decomposition

7. SPECIAL FUNCTIONS

In this section we list the special functions (S functions) used in CONIFER. The section consists of two parts. The first is a cross-reference list of S functions indicating the G and Y functions in which each S is used. In the second part we define the S functions algebraically.

7.1. *Cross-Reference Listing of Special Functions*

S_1 saturation vapor pressure as function of temperature -- G_2, G_{14}, G_{21}, G_{99}

S_2 beta function -- G_{39}, G_{40}, G_{53}, G_{77}, G_{102}

S_3 weekly averaging function -- G_{41}, G_{48}, G_{49}, G_{51}, G_{58}, G_{107}, G_{108}, G_{109}, G_{110}, G_{144}, Y_1, Y_2, Y_4, Y_5, Y_{14}, Y_{17}, Y_{18}, Y_{19}

S_4 longwave radiation from blackbody -- G_{121}, G_{122}

S_5 table look-up function for albedo of snowpack -- G_{118}

S_6 delta function -- G_{40}, G_{44}, G_{93}, G_{135}

7.2. *Descriptions of S Functions*

S_1 = saturation vapor pressure as function of temperature

$$S_1(T_1) = B_{153} \exp \left(\frac{B_{72}T_1}{T_1 + B_{18}}\right)$$

T_1 = arbitrary temperature (deg)
B_{18} = coefficient in Teten's equation (deg)
B_{72} = coefficient in Teten's equation (dim.)
B_{153} = vapor pressure over water at 0°C (mbar)

Comment: S_1 is Teten's equation for saturation vapor pressure as a function of temperature (Murray 1967).

S_2 = beta function

$$S_2(T_1, T_2, T_3, T_4) = \begin{cases} (T_1 - T_2)(T_3 - T_1)^{T_4-1} & \text{if } T_2 \geq T_1 \leq T_3 \\ 0 & \text{otherwise} \end{cases}$$

T_1, T_2, T_3, and T_4 = arbitrary parameters

S_3 = weekly averaging function

$$S_3(i, T_1) = \begin{cases} \text{weekly average of } T_1 & \text{if } t_d \text{ modulo } 7 = 1 \\ T_1 & \text{if } t_d = 1 \\ 0 & \text{otherwise} \end{cases}$$

T_1 = arbitrary parameter
t_d = time (days)
i = index for keeping separate each instance in which S_3 is used

Comment: Function is designed to compute weekly average value of variables that are computed daily. T_1 may be a G, a Z, or a Y. A sum must be accumulated for seven days in order to compute the average and it is necessary to have a separate sum for each instance in which the function is used. This vector of sums is called DAILY in the code. The allocation of elements of DAILY is shown below.

i	variable
1	G_{49}
2	G_{109}
3	G_{110}
4	G_{107}
5	G_{108}
6	G_{48}
7	G_{58}
10	Y_1
11	Y_2
12	G_{80}
13	Y_4
14	Y_5
15	Y_{17}
16	Y_{14}
17	Y_{18}
18	Y_{19}

S_4 = longwave radiation from blackbody (ly/day)

$$S_4(T_1) = 1.17 \times 10^{-7}(T_1 + 273.16)^4$$

T_1 = arbitrary temperature

Comment: We assume emissivity of 1.0 in all calculations.

S_5 = table look-up function for albedo of snowpack (see G_{118})

$S_6(T_1, T_2, T_3)$ = delta function

$$S_6(T_1, T_2, T_3) = \begin{cases} T_3 & \text{if } t_d = T_1 \text{ or } t_d = T_2 \\ 0 & \text{otherwise} \end{cases}$$

T_1, T_2, and T_3 = arbitrary parameters
t_d = time in days

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8. OUTPUT VARIABLES

In this section we list the output variables and functions (Y's) that we have included in CONIFER. These functions are not necessary for the operation of CONIFER; they are simply the functions that, in the course of working with the model over some three years, we have found useful and convenient.

Y_1 = weekly evaporation from litter and canopy ($m^3 \cdot ha^{-1} \cdot wk^{-1}$)

$$Y_1 = 7S_3(10, G_7 + G_8 + G_{22})$$

G_7 = evaporation from foliar surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_8 = evaporation from epiphyte and bark surfaces ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
G_{22} = evaporation from litter ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
S_3 = weekly averaging function

Y_2 = weekly transpiration ($m^3 \cdot ha^{-1} \cdot wk^{-1}$)

$$Y_2 = 7S_3(11, G_{20})$$

G_{20} = transpiration ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
S_3 = weekly averaging function

Y_4 = weekly precipitation ($m^3 \cdot ha^{-1} \cdot wk^{-1}$)

$$Y_4 = 7S_3(13, Z_1)$$

Z_1 = total precipitation ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
S_3 = weekly averaging function

Y_5 = weekly snowfall ($m^3 \cdot ha^{-1} \cdot wk^{-1}$)

$$Y_5 = 7S_3(14, G_{115})$$

G_{115} = precipitation as snow ($m^3 \cdot ha^{-1} \cdot day^{-1}$)
S_3 = weekly averaging function

Y_6 = total litter respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$Y_6 = G_{103} + G_{111} + G_{113} + G_{125}$$

G_{103} = carbon loss from foliage litter due to respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{111} = carbon loss from woody litter due to respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{113} = carbon loss from logs due to respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{125} = carbon loss from fine litter due to respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

Y_7 = total soil respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$Y_7 = G_{131} + G_{133} + G_{139} + G_{140}$$

G_{131} = carbon loss from dead roots due to respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{133} = carbon loss from rooting zone organic matter due to respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{139} = large root respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{140} = fine root respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

Y_9 = net new foliage assimilation ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$Y_9 = G_{24} - G_{25}$$

G_{24} = net new foliage photosynthesis ($t \cdot ha^{-1}\ wk^{-1}$)
G_{25} = new foliage nighttime respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

Y_{10} = net old foliage assimilation ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$Y_{10} = G_{29} - G_{30}$$

G_{29} = net old foliage photosynthesis ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{30} = old foliage nighttime respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

Y_{11} = total plant respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$Y_{11} = G_{25} + G_{31}$$

G_{25} = new foliage nighttime respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{31} = total respiration loss from growth CH_2O pool ($t \cdot ha^{-1} \cdot wk^{-1}$)

Y_{12} = total forest floor respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$Y_{12} = G_{103} + G_{111} + G_{113} + G_{125} + G_{131} + G_{133} + G_{139} + G_{140}$$

G_{103} = carbon loss from foliage litter due to respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{111} = carbon loss from woody litter due to respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{113} = carbon loss from logs due to respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{125} = carbon loss from fine litter due to respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{131} = carbon loss from dead roots due to respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{133} = carbon loss from rooting zone organic matter due to respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{139} = large root respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{140} = fine root respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

Y_{14} = weekly average of litter water as percent of holding capacity (dim.)

$$Y_{14} = S_3[16, (X_7/G_{55})100]$$

X_7 = litter water (m^3/ha)
G_{55} = water-holding capacity of litter (m^3/ha)
S_3 = weekly averaging function

Y_{15} = soil water as percent of holding capacity (dim.)

$$Y_{15} = 100X_3/B_{13}$$

X_3 = soil rooting zone water (m^3/ha)
B_{13} = water retention capacity of soil (m^3/ha)

Y_{16} = net assimilation ($t \cdot ha^{-1} \cdot wk^{-1}$)

$$Y_{16} = G_{24} - G_{25} + G_{29} - G_{30}$$

G_{24} = net new foliage photosynthesis ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{25} = new foliage nighttime respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{29} = net old foliage photosynthesis ($t \cdot ha^{-1} \cdot wk^{-1}$)
G_{30} = old foliage nighttime respiration ($t \cdot ha^{-1} \cdot wk^{-1}$)

Y_{17} = weekly average of percent shortwave radiation intercepted by canopy (dim.)

$$Y_{17} = S_3(15, T_1)$$

T_1 = percent of shortwave radiation intercepted by canopy (dim.)

$$T_1 = 100(1 - G_{91}/G_{59})$$

G_{59} = net shortwave radiation at top of canopy (ly/day)

G_{91} = shortwave radiation incident to snowpack or litter (ly/day)
S_3 = weekly averaging function

Y_{18} = weekly average of water stored on foliage (m^3/ha)

$$Y_{18} = S_3(17, X_1)$$

X_1 = water storage on foliage (m^3/ha)
S_3 = weekly averaging function

Y_{19} = weekly average of water stored on bark and epiphyte surfaces (m^3/ha)

$$Y_{19} = S_3(18, X_8)$$

X_8 = water storage on epiphyte and bark surfaces (m^3/ha)
S_3 = weekly averaging function

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9. PARAMETERS AND PARAMETER VALUES

In this section we have listed all parameters used in CONIFER. Parameters in CONIFER are of two types: integer (*M* parameters) and decimal (*B* parameters). The *M* parameters are used exclusively to specify the timing of processes. Immediately following the description of each parameter, we have listed the functions (*G*'s, *S*'s, and *Y*'s) in which the parameter is used. On the right-hand side are shown the numerical value of each parameter and (for *B* parameters) the units.

B_1	coefficient for attenuation of shortwave radiation by understory -- G_{91}	1.5 ha/t
B_2	coefficient for attenuation of shortwave radiation by overstory -- G_{91}	1.0 ha/t
B_3	ratio of canopy water retention capacity to foliar carbon mass -- G_{16}	1.34 m^3/t
B_4	fraction of total foliage occurring in overstory -- G_{91}	0.7 (dim.)
B_5	soil moisture value below which transpiration ceases -- G_{20}, G_{42}	1819 m^3/ha
B_6	temperature threshhold below which albedo of snowpack is set equal to 0.8 -- G_{118}	3 deg
B_7	ratio of one-sided needle surface area to needle carbon mass -- G_1	1.54 ha/t
B_9	rate constant for soil water drainage -- G_{12}	2.16 day^{-1}

B_{10}	rate constant for subsoil water drainage -- G_{19}	1.08 day^{-1}
B_{11}	fraction of litter water-holding capacity below which there is resistance to evaporation -- G_{22}	0.36 (dim.)
B_{12}	fraction of litter water-holding capacity below which evaporation ceases -- G_{22}	0.10 (dim.)
B_{13}	water retention capacity of soil -- G_{12}, Y_{15}	3204 m^3/ha
B_{14}	water retention capacity of subsoil -- G_{19}	9970 m^3/ha
B_{15}	increase in ratio of rainfall to total precipitation with temperature -- G_{54}	0.172 deg^{-1}
B_{16}	retention capacity of groundwater zone -- G_{18}	11,896 m^3/ha
B_{17}	temperature above which all precipitation is rain -- G_{54}	3.3 deg
B_{18}	coefficient in Teten's equation -- G_{17}, S_1	237.3 deg
B_{19}	temperature below which all precipitation is snow -- G_{54}	-2.5 deg
B_{20}	fraction of litter water-holding capacity below which drainage ceases -- G_{15}	0.7 (dim.)
B_{21}	ratio of snowmelt due to convection to the difference between air and snow temperature -- G_{170}	0.051 $g \cdot cm^{-2} \cdot day^{-1} \cdot deg^{-1}$
B_{22}	ratio of snowmelt due to condensation to vapor pressure deficit at snow surface -- G_2	0.28 $g \cdot cm^{-2} \cdot day^{-1} \cdot mbar^{-1}$
B_{23}	ratio of litter water-holding capacity to litter carbon mass -- G_{55}	4.6 m^3/t
B_{24}	factor such that G_{77} averages 1.0 during first year -- G_{77}	0.036 $deg^{-B_{181}}$
B_{25}	length of longest day minus twelve -- G_{123}	3.5 hr
B_{26}	foliar respiration rate constant -- G_{25}, G_{30}	0.0219 wk^{-1}
B_{27}	ratio of old foliage to new foliage respiration -- G_{30}	1.11 (dim.)
B_{28}	maximum respiration rate of stems plus branches -- G_{138}	0.215 $t \cdot ha^{-1} \cdot wk^{-1}$
B_{29}	maximum respiration rate of large roots -- G_{139}	0.078 $t \cdot ha^{-1} \cdot wk^{-1}$
B_{30}	rate constant for fine root respiration -- G_{140}	6.36×10^{-3} wk^{-1}
B_{31}	bud growth rate constant -- G_{33}	3.23×10^{-4} wk^{-1}

B_{32}	ratio of net new foliage photosynthesis based on carbon budget to amount extrapolated from cuvette experiments -- G_{24}, G_{29}	13.05 (dim.)
B_{33}	rate constant for new foliage photosynthesis -- G_{24}	5.68×10^{-4} sec·cm^{-1}·deg$^{-B_{177}}$·wk^{-1}
B_{34}	light intensity at which new foliage photosynthesis is one-half maximum rate -- G_{24}	0.1 ly/min
B_{35}	coefficient for attenuation of shortwave radiation by foliage -- G_{24}, G_{29}	0.52 ha/t
B_{36}	factor such that G_{39} averages 1.0 over the first year -- G_{39}	0.0386 deg$^{-B_{77}}$
B_{37}	ratio of leaf carbon mass to bud carbon -- G_{44}, G_{46}	120 (dim.)
B_{38}	rate at which new foliage growth demand decreases as new foliage carbon mass approaches limiting value -- G_{46}	0.3 wk^{-1}
B_{39}	maximum rate of carbon transfer from growth CH_2O pool to new foliage CH_2O pool -- G_{45}	0.38 t·ha^{-1}·wk^{-1}
B_{40}	value of growth CH_2O pool at which transfer to new foliage pool is one-half maximum -- G_{45}	0.1 t/ha
B_{41}	rate constant for old foliage photosynthesis -- G_{29}	6.24×10^{-4} sec·cm^{-1}·deg$^{-B_{177}}$·wk^{-1}
B_{42}	shortwave radiation value at which old foliage photosynthesis is one-half maximum -- G_{29}	0.1 ly/min
B_{43}	factor such that G_{40} integrated over one year is 1.0 assuming no defoliation -- G_{40}	2.48×10^{-23} wk$^{-(B_{91}+1)}$
B_{44}	value of growth pool at which old foliage respiration is one-half maximum -- G_{30}	0.1 t/ha
B_{45}	maximum rate of carbon transfer from growth CH_2O pool to stems plus branches -- G_{35}	0.3780 t·ha^{-1}·wk^{-1}
B_{46}	value of growth pool at which respiration of and transfer to stems plus branches is one-half maximum -- G_{35}, G_{138}	6.0 t/ha
B_{47}	maximum rate of carbon transfer from growth CH_2O pool to large roots -- G_{36}	0.095 t·ha^{-1}·wk^{-1}
B_{48}	value of growth pool at which respiration of and transfer to large roots is one-half maximum -- G_{36}, G_{139}	6.0 t/ha
B_{49}	maximum rate of carbon transfer from growth CH_2O pool to fine roots -- G_{37}	0.0295 t·ha^{-1}·wk^{-1}

B_{50}	value of growth pool at which respiration of and transfer to fine roots is one-half maximum -- G_{37}, G_{140}	0.07 t/ha
B_{51}	rate constant for stem-plus-branch mortality -- G_{62}, G_{92}	4.47×10^{-4} wk^{-1}
B_{52}	rate constant for large root mortality -- G_{86}	3.9×10^{-4} wk^{-1}
B_{53}	rate constant for fine root mortality -- G_{87}	0.00257 wk^{-1}
B_{54}	factor such that G_{53} averages 1.0 during the first year -- G_{53}	0.0361 $deg^{-B_{179}}$
B_{56}	rate constant for new foliage consumption -- G_{38}	0.0014 wk^{-1}
B_{57}	rate constant for old foliage consumption -- G_{90}	0.0001 wk^{-1}
B_{58}	rate constant for consumption of growth CH_2O pool -- G_{94}	0.0001 wk^{-1}
B_{59}	rate constant for bud consumption -- G_{95}	0.0001 wk^{-1}
B_{60}	ratio of old to new foliage stomatal resistance -- G_{52}	1.1 (dim.)
B_{61}	rate constant for woody litter decomposition -- G_{69}	0.00177 wk^{-1}
B_{62}	rate constant for foliage litter decomposition -- G_{81}	0.00247 wk^{-1}
B_{63}	rate constant for fine litter decomposition -- G_{84}	0.00384 wk^{-1}
B_{64}	fraction of carbon loss from fine litter due to incorporation into soil rooting zone organic matter -- G_{116}, G_{125}	0.25 (dim.)
B_{65}	rate constant for decomposition of soil rooting zone organic matter -- G_{88}	0.00118 wk^{-1}
B_{66}	fraction of carbon loss from soil rooting zone due to incorporation into subsoil organic matter -- G_{132}, G_{133}	0.25 (dim.)
B_{67}	factor such that soil moisture--temperature effect averages 1.0 over first year -- G_{50}	2662 m^3/ha
B_{68}	rate constant for dead root decomposition -- G_{85}	0.00913 wk^{-1}
B_{69}	fraction of carbon loss from dead roots due to fragmentation -- G_{126}, G_{131}	0.5 (dim.)
B_{71}	factor such that $B_{71}G_{39}$ averages 1.0 during the first-year growing season -- G_{46}	0.564 (dim.)

B_{72}	coefficient in Teten's equation -- G_{17}, S_1	17.27 (dim.)
B_{73}	weekly throughfall amount above which soil temperature equals air temperature -- G_{68}	150 $m^3 \cdot ha^{-1} \cdot day^{-1}$
B_{74}	water-holding capacity per unit carbon mass for woody litter divided by the same ratio for foliage plus fine litter -- G_{55}	0.25 (dim.)
B_{75}	rate constant for frass fall -- G_{82}	0.05 wk^{-1}
B_{76}	temperature above which growth processes cease -- G_{39}	45 deg
B_{77}	coefficient determining shape of G_{39} curve -- G_{39}	1.35 (dim.)
B_{78}	minimum plant moisture stress (PMS) -- G_{42}, G_{87}	4.7 atm
B_{79}	air temperature above which PMS is unaffected by temperature -- G_{42}	-2.0 deg
B_{82}	soil moisture value above which PMS does not change -- G_{42}	2104 m^3/ha
B_{84}	maximum PMS -- G_{42}	32.7 atm
B_{85}	rate of increase of PMS with increasing soil moisture content -- G_{42}	0.09825 $atm \cdot ha^{-1} \cdot m^{-3}$
B_{86}	maximum new foliage stomatal resistance -- G_{43}	300 sec/cm
B_{87}	PMS above which there is no increase in new foliage resistance -- G_{43}	19 atm
B_{88}	new foliage stomatal resistance when PMS is 0.0 -- G_{43}	1.9435 sec/cm
B_{89}	coefficient for effect of PMS on new foliage stomatal resistance -- G_{43}	0.265 atm^{-1}
B_{91}	coefficient for shape of leaf-fall curve -- G_{40}	13.0 (dim.)
B_{92}	factor for effect of air temperature on litter temperature -- G_{67}	0.5 wk^{-1}
B_{93}	weekly throughfall amount above which litter temperature equals air temperature -- G_{67}	3000 $m^3 \cdot ha^{-1} \cdot wk^{-1}$
B_{94}	factor such that G_{69} averages 1.0 during the first year -- G_{69}	0.1494 ha/m^3
B_{95}	factor for effect of litter temperature on soil temperature -- G_{68}	0.1 wk^{-1}
B_{141}	coefficient for effect of temperature on plant nonfoliar respiration -- G_{138}, G_{139}, G_{140}	0.069 deg^{-1}
B_{145}	coefficient for temperature effect on foliar respiration -- G_{25}, G_{30}	0.073 deg^{-1}

B_{146}	rate constant for log litter decomposition -- G_{105}	0.00122 wk^{-1}
B_{147}	fraction of carbon loss from log litter due to fragmentation -- G_{112}, G_{113}	0.5 (dim.)
B_{148}	fraction of carbon loss from woody litter due to fragmentation -- G_{104}, G_{111}	0.6 (dim.)
B_{149}	fraction of carbon loss from foliage litter due to fragmentation -- G_{98}, G_{103}	0.4 (dim.)
B_{150}	fraction of stem-plus-branch mortality transferred to woody litter -- G_{62}, G_{92}	0.228 (dim.)
B_{152}	rate of input of carbon to fine litter in microparticulate litterfall and carbon dissolved in throughfall -- G_{97}	2.885×10^{-3} $t \cdot ha^{-1} \cdot wk^{-1}$
B_{153}	vapor pressure over water at 0°C -- S_1	6.11 mbar
B_{154}	density of saturated air -- G_{14}, G_{99}	1.2 kg/m^3
B_{155}	specific heat of saturated air -- G_{14}, G_{99}	1000 $joule \cdot kg^{-1} \cdot deg^{-1}$
B_{156}	wind profile drag coefficient -- G_{100}	0.3 (dim.)
B_{157}	latent heat of vaporization of water -- G_6, G_{14}, G_{20}	2.5×10^6 joule/kg
B_{158}	psychrometric constant -- G_6, G_{14}, G_{20}	0.66 mbar/deg
B_{159}	factor to convert $kg \cdot m^{-2} \cdot sec^{-1}$ to $m^3 \cdot ha^{-1} \cdot day^{-1}$ -- G_6, G_{14}, G_{20}	8.64×10^5 $sec \cdot m^{-5} \cdot day^{-1} \cdot kg^{-1} \cdot ha^{-1}$
B_{160}	albedo of canopy -- G_{59}	0.1 (dim.)
B_{163}	aerodynamic conductance at litter surface -- G_{14}	0.001 m/sec
B_{164}	factor to convert net radiation from ly/day to $joule \cdot m^{-2} \cdot sec^{-1}$ -- G_6, G_{20}	0.48 joule $day \cdot m^{-2} \cdot sec^{-1} \cdot ly^{-1}$
B_{165}	rate constant for drainage from litter -- G_{15}	10 day^{-1}
B_{166}	first day on which new foliage is to be removed (defoliation perturbation only) -- G_{44}, G_{135}	0
B_{167}	fraction by which new foliage is to be reduced during acute defoliation perturbation -- G_{44}, G_{135}	0 (dim.)
B_{169}	second day on which new foliage is to be removed (defoliation perturbation only) -- G_{44}, G_{135}	0
B_{170}	rate constant for water drainage from canopy -- G_5, G_{56}	10.0 day^{-1}
B_{171}	water storage on foliage above which there is no transpiration -- G_{20}	1.0 m^3/ha

B_{172}	ratio of intercepting area to carbon mass for stems plus branches divided by same ratio for foliage -- G_{13}, G_{23}	0.01 (dim.)
B_{173}	ratio of storage capacity to carbon mass for stems plus branches divided by same ratio for foliage -- G_{16}, G_{57}	0.015 (dim.)
B_{174}	coefficient for effect of foliar carbon mass on intercepting area -- G_{23}	0.19 ha/t
B_{176}	temperature above which photosynthesis ceases -- G_{102}	45 deg
B_{177}	coefficient determining shape of G_{102} -- G_{102}	2.5 (dim.)
B_{178}	temperature above which soil rooting zone processes cease -- G_{53}	45 deg
B_{179}	coefficient for temperature effect on soil rooting zone processes -- G_{53}	1.35 (dim.)
B_{180}	temperature above which litter decomposition ceases -- G_{77}	45 deg
B_{181}	coefficient for temperature effect on litter decomposition -- G_{77}	1.35 (dim.)
B_{182}	minimum leaf-fall rate constant -- G_{40}	0.003 wk^{-1}
B_{183}	ratio of photosynthetically active radiation to total shortwave radiation -- G_{109}	0.4 (dim.)
B_{184}	fraction by which old foliage is reduced during acute defoliation perturbation -- G_{93}	0 (dim.)
B_{185}	first day on which old foliage is removed (defoliation perturbation only) -- G_{93}	0
B_{186}	second day on which old foliage is removed (defoliation perturbation only) -- G_{93}	0
M_1	week on which budbreak occurs -- G_{44}	18
M_2	week on which growing season begins -- G_{106}	18
M_3	week on which growing season ends -- G_{106}	40
M_4	week on which new foliage becomes old foliage -- G_{34}	40
M_5	week on which leaf-fall is minimum -- G_{40}	35

10. ACKNOWLEDGMENTS

CONIFER is a product of four years of research by various people employed by and associated with the Coniferous Forest Biome, Ecosystem Analysis Studies, U.S./International Biological Program (U.S./IBP). The project was initially supervised by W. S. Overton of Oregon State University (OSU) who developed the notational scheme and much of the methodology. By summer 1973 Overton and co-workers (C. E. White and J. Colby) had implemented a model of water flow based on earlier versions by J. P. Riley and G. B. Shih of Utah State University. In the spring of 1973 P. Sollins joined the project at the University of Washington (UW) and brought with him a carbon flow model which he had developed at Oak Ridge National Laboratory. With C. E. White (OSU) and K. L. Reed (then of UW), he reorganized and substantially improved the Oak Ridge version. In the fall 1973, G. L. Swartzman joined the project (at UW) and proceeded to combine Overton's hydrology model with Sollins' model of production and decomposition. At this time Swartzman added the litter and soil temperature component and Sollins added equations for predicting stomatal resistance based on the work of R. H. Waring and S. W. Running (both of OSU). Some initial problems with the coupled carbon-water model were traced to inadequate representation of snowmelt and, with the help of J. Rogers (USDA Forest Service), Swartzman incorporated the snowmelt model of Leaf and Brink (1973) into CONIFER.

During spring 1974 Swartzman, working with P. G. Jarvis (on leave from the University of Edinburgh), incorporated mechanistic equations for transpiration and evaporation from the canopy. Swartzman, working with R. Fogel and K. Cromack (both of OSU), also developed preliminary equations for drainage and evaporation from litter. Later that spring Sollins constructed a new model of canopy interception and storage and with Swartzman wrote improved equations for drainage from canopy, litter, and soil water pools.

Over the next year various improvements and refinements were made with the help of various programmers at UW including, E. Hamerly and M. Gaponoff. The basic documentation system was developed jointly by Swartzman and Sollins; however, implementation would have been impossible without the conscientious assistance of staff and students including M. Roscoe, D. Dodson, K. Nicholson, E. Small, and R. Harr. In 1975 S. Clark joined the UW project as a programmer and totally reorganized the code for CONIFER. Clark developed the module system and, with E. Small, developed the tree diagrams used here. Most aspects of the code showing systematic organization reflect the single-handed efforts of S. Clark. The final preparation of this bulletin was supervised by P. Sollins.

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APPENDIX I. Listing of Code

The code listing of Appendix I is reproduced directly from computer output.

```
C
C*************************************************************************
C
C
C           COMMON BLOCK ASSIGNMENT. UNDER SIMCOMP, ALL COMMON BLOCKS
C           DEFINED HERE ARE AVAILABLE TO ALL SUBROUTINES WITH NO
C           EXPLICIT REFERENCE NECESSARY IN THOSE ROUTINES.
C
C              /GVAR/   INTERMEDIATE VARIABLES        G
C              /BVAR/   PARAMETER VALUES              P
C              /MVAR/   INTEGER PARAMETER VALUES      M
C              /ZVAR/   DRIVING VARIABLES             Z
C              /YVAR/   OUTPUT VARIABLES              Y
C              /TIME/   TIMING VARIABLES
C
      COMMON /BVAR/ B(225)
      COMMON /MVAR/ M(5)
      COMMON /ZVAR/ Z(25)
      COMMON /YVAR/ Y(30)
      COMMON /TIME/ K,KMO,KWK,KT,KT1,KTW
      COMMON /GVAR/ G(200)
C
C
C*************************************************************************
C
      SUBROUTINE CYCL1
C
      CALL TIMER
      CALL ZUP
      CALL GUP
      CALL YUP
C
      RETURN
      END
C
C*************************************************************************
C
      SUBROUTINE GUP
C
C                 THIS SUBROUTINE UPDATES ALL INTERMEDIATE (G) FUNCTIONS
C
C
C
C-------------------------------------------------------------------------
C     WATER - CANOPY INTERCEPTION AND RETENTION  [ MODULE 1 ]
C-------------------------------------------------------------------------
C
C
C
C---G(61)---------- TOTAL FOLIAGE CARBON
$O               ,G(61)$
$I               ,X(10),X(11)$
C
      G(61) = X(10) + X(11)
C
C
C---G(23)---------- PERCENT COVER BY CANOPY (ALSO PERCENT COVER BY
C                   OVERSTORY)
$O            ,G(23)$
```

```
$I          ,G(61),X(13)$
C
      T1 = -B(174) * ( G(61) + B(172) * X(13) )
      G(23) = 1.0 - EXP ( T1 )
C
C
C---G(13)---------- FRACTION OF RAIN INCIDENT TO CANOPY WHICH STRIKES
C                  FOLIAGE
$O          ,G(13)$
$I          ,G(61),X(13)$
C
      G(13) = G(61) / ( G(61) + B(172) * X(13) )
C
C
C---G(54)---------- PRECIPITATION AS RAIN
$O              ,G(54)$
$I              ,Z(1),Z(6),Z(4),Z(7)$
C
      T1 = B(15) * Z(1) * Z(4) * ( Z(6) - B(19) )
      T2 = B(15) * Z(1) * ( 1.0 - Z(4) ) * ( Z(7) - B(19) )
      IF ( Z(6) .LT. B(19) )
     >   G(54) = 0.0
      IF ( Z(7) .GT. B(17) )
     >   G(54) = Z(1)
      IF ( Z(6) .LE. B(17) .AND. Z(7) .GE. B(19) )
     >   G(54) = T1 + T2
      IF ( Z(7) .LT. B(19) .AND. B(19) .LT. Z(6) .AND.
     >     Z(6) .LE. B(17) )
     >   G(54) = T1
      IF ( Z(6) .GT. B(17) .AND. B(17) .GE. Z(7) .AND.
     >     Z(7) .GE. B(19) )
     >   G(54) = Z(1) * Z(4) + T2
C
C
C---G(115)--------- PRECIPITATION AS SNOW
$O              ,G(115)$
$I              ,Z(1),G(54)$
C
      G(115) = Z(1) - G(54)
C
C
C---G(60)---------- SNOWPACK ICE PLUS CURRENT DAYS SNOWFALL
$O              ,G(60)$
$I              ,X(2),G(115)$
C
      G(60) = X(2) + G(115)
C
C
C---G(160)--------- SNOW SURFACE TEMPERATURE
$O              ,G(160)$
$I              ,G(60),X(37)$
C
      G(160) = 0.0
C
C
C---G(3)---------- RAIN INPUT TO FOLIAR SURFACES
$O          ,G(3)$
$I          ,G(23),G(13),G(54)$
C
      G(3) = G(23) * G(13) * G(54)
```

```
C
C
C---G(4)---------- RAIN INPUT TO EPIPHYTE AND BARK SURFACES
$O          ,G(4)$
$I          ,G(23),G(13),G(54)$
C
      G(4) = G(23) * ( 1.0 - G(13) ) * G(54)
C
C
C
C
C-----------------------------------------------------------------------
C     SHORT-WAVE RADIATION TO CANOPY AND          [ MODULE 1 ]
C          LONG-WAVE ENERGY BALANCE
C-----------------------------------------------------------------------
C
C
C
C---G(41)---------- LITTER TEMPERATURE
$O             ,G(41)$
$I             ,X(25)$
C
      G(41) = X(25)
C
C
C---G(121)--------- HEAT LOSS FROM SNOWPACK OR LITTER DUE TO LONGWAVE
C                  RADIATION
$O             ,G(121)$
$I             ,G(60),X(25)$
$E             ,S4$
C
      T1 = G(160)
      IF ( G(60) .LE. 0.0 )
     >   T1 = X(25)
      G(121) = S4 ( T1 )
C
C
C---G(122)--------- LONGWAVE RADIATION FROM BLACK BODY AT AIR TEMP.
$O             ,G(122)$
$I             ,Z(3)$
$E             ,S4$
C
      G(122) = S4 ( Z(3) )
C
C
C---G(123)--------- LONGWAVE RADIATION FROM SKY
$O             ,G(123)$
$I             ,TIME,Z(2),G(122)$
C
      T1 = SIN ( 0.01721 * ( TIME - 79.01721 ) )
      T2 = ( B(25) * T1 + 12.0 ) / 24.0
      IF ( Z(2) .GE. T2 .AND. Z(2) .LE. 1.6 * T2 )
     >   GO TO 12310
C     ELSE
         T3 = 0.76
         IF ( Z(2) .LT. T2 )
     >      T3 = 1.0
         GO TO 12320
12310 CONTINUE
         T3 = 0.76 + 0.4 * ( 1.6 * T2 - Z(2) ) / T2
```

```
C
12320 G(123) = T3 * G(122)
C
C
C---G(124)--------- NET HEAT TRANSFER FROM CANOPY TO SNOWPACK OR LITTER
C                   DUE TO LONGWAVE RADIATION
$O              ,G(124)$
$I              ,G(23),G(122),G(121)$
C
      G(124) = G(23) * ( G(122) - G(121) )
C
C
C---G(168)--------- NET HEAT TRANSFER FROM SKY TO CANOPY DUE TO LONG-
C                   WAVE RADIATION
$O              ,G(168)$
$I              ,G(122),G(23),G(123)$
C
      G(168) = G(23) * ( G(123) - G(122) )
C
C
C---G(59)---------- NET SHORTWAVE RADIATION AT TOP OF CANOPY
$O              ,G(59)$
$I              ,Z(2),Z(4)$
C
      G(59) = 1440.0 * Z(2) * Z(4) * ( 1.0 - B(160) )
C
C
C---G(91)---------- SHORTWAVE RADIATION INCIDENT TO SNOWPACK OR LITTER
$O              ,G(91)$
$I              ,G(61),G(59),G(23)$
C
C               T1 = ATTENUATION BY UNDERSTORY
C
      T1 = EXP ( -B(1) * G(61) * ( 1.0 - B(4) ) )
C
C               T2 = ATTENUATION BY OVERSTORY
C
      T2 = EXP ( - B(2) * G(61) * B(4) )
C
      G(91) = G(59) * T1 * (  1.0 - G(23) * ( 1.0 - T2 )  )
C
C
C---G(118)--------- ALBEDO OF SNOW OR LITTER
$O              ,G(118)$
$I              ,X(2)$
$F              ,S5$
C
      T1 = 0.0
      IF ( X(2) .LE. 10.0 )
     >   T1 = 1.0
      G(118) = S5 ( T1 )
C
C
C---G(119)--------- NET HEAT TRANSFER FROM CANOPY TO SNOWPACK OR LITTER
C                   DUE TO SHORTWAVE RADIATION
$O              ,G(119)$
$I              ,G(91),G(118)$
C
      G(119) = G(91) * ( 1.0 - G(118) )
C
```

```
C
C---G(169)--------- HEAT INPUT TO CANOPY FROM LONG + SHORT WAVE RADIATIO
$O              ,G(169)$
$I              ,G(168),G(124),G(59),G(119)$
C
      G(169) = G(168) + G(59) - G(124) - G(119)
C
C
C
C
C-----------------------------------------------------------------------
C     WATER - CANOPY EVAPORATION AND DRIP        [ MODULE 3 ]
C-----------------------------------------------------------------------
C
C
C
C---G(21)---------- SATURATION VAPOR PRESSURE AT AIR TEMPERATURE
$O           ,G(21)$
$I           ,Z(3)$
$E           ,S1$
C
      G(21) = S1 ( Z(3) )
C
C
C---G(17)---------- RATE OF CHANGE OF SATURATION VAPOR PRESSURE WITH
C                   TEMPERATURE
$O           ,G(17)$
$I           ,G(21),Z(3)$
C
      G(17) = B(18) * B(72) * G(21) / ( Z(3) + B(18) )**2
C
C
C---G(99)---------- VAPOR PRESSURE DEFICIT
$O              ,G(99)$
$I              ,G(21),Z(5)$
$E              ,S1$
C
      T1 = G(21) - S1 ( Z(5) )
      G(99) = B(154) * B(155) * T1
C
C
C---G(100)--------- AERODYNAMIC RESISTANCE
$O              ,G(100)$
$I              ,Z(14)$
C
      G(100) = 1.E6
      IF ( Z(14) .NE. 0.0 )
     >   G(100) = 1.0 / ( Z(14) * B(156)**2 )
C
C
C---G(6)---------- POTENTIAL EVAPORATION FROM CANOPY
$O           ,G(6)$
$I           ,G(17),G(169),Z(4),G(99),G(100)$
C
      T1 = B(159) * ( G(17) * G(169) * B(164) * Z(4) + G(99) / G(100) )
      T2 = B(157) * ( G(17) + B(158) )
      G(6) = AMAX1 ( 0.0 , T1 / T2 )
C
C
C---G(16)---------- WATER RETENTION CAPACITY OF CANOPY
```

```
$O          ,G(16)$
$I          ,G(61),X(13)$
C
      G(16) = B(3) * ( G(61) + B(173) * X(13) )
C
C
C---G(57)---------- FRACTION OF RETENTION CAPACITY DUE TO FOLIAGE
$O               ,G(57)$
$I               ,G(61),X(13)$
C
      G(57) = G(61) / ( G(61) + B(173) * X(13) )
C
C
C---G(5)---------- DRIP FROM FOLIAR SURFACES
$O          ,G(5)$
$I          ,X(1),G(16),G(3),G(57),G(6)$
C
      T1 = 1.0 - EXP ( -B(170) )
      T2 = X(1) - G(16) * G(57)
      T3 = G(3) - G(57) * G(6)
      T4 = 1.0 - T1 / B(170)
      G(5) = AMAX1 (  0.0  ,  T1 * T2 + T3 * T4  )
C
C
C---G(7)---------- EVAPORATION FROM FOLIAR SURFACES
$O          ,G(7)$
$I          ,G(6),G(57),G(5),X(1),G(3)$
C
      G(7) = G(6) * G(57)
      IF ( G(5) .GT. X(1) + G(3) - G(7) )
     >   G(7) = X(1) + G(3) - G(5)
C
C
C---G(71)---------- DRIP FROM FOLIAR SURFACES TO LITTER SURFACES WATER
$O               ,G(71)$
$I               ,G(5),G(60)$
C
      G(71) = G(5)
      IF ( G(60) .GT. 0.0 )
     >   G(71) = 0.0
C
C
C---G(56)---------- DRIP FROM EPIPHYTE AND BARK SURFACES
$O               ,G(56)$
$I               ,X(8),G(16),G(57),G(4),G(6)$
C
      T1 = 1.0 - EXP ( -B(170) )
      T2 = 1.0 - G(57)
      T3 = ( G(4) - G(6) * T2 )  *  ( 1.0 - T1 / B(170) )
      G(56) = AMAX1 (  0.0 , T3  +  T1 * ( X(8) - G(16) * T2 )  )
C
C
C---G(8)---------- EVAPORATION FROM EPIPHYTE AND BARK SURFACES
$O          ,G(8)$
$I          ,G(6),G(57),G(56),X(8),G(4)$
C
      G(8) = G(6) * ( 1.0 - G(57) )
      IF ( G(56) .GT. X(8) + G(4) - G(8) )
     >   G(8) = X(8) + G(4) - G(56)
C
```

```
C
C---G(72)---------- DRIP FROM EPIPHYTE AND BARK SURFACES TO LITTER
C                   SURFACE WATER
$O             ,G(72)$
$I             ,G(56),G(60)$
C
      G(72) = G(56)
      IF ( G(60) .GT. 0.0 )
     >   G(72) = 0.0
C
C
C
C
C-----------------------------------------------------------------------
C     ENERGY INPUT TO SNOW                          [ MODULE 4 ]
C-----------------------------------------------------------------------
C
C
C
C---G(9)---------- RAINFALL PASSING DIRECTLY TO SNOWPACK OR LITTER
C                  SURFACES
$O          ,G(9)$
$I          ,G(23),G(54)$
C
      G(9) = ( 1.0 - G(23) ) * G(54)
C
C
C---G(134)--------- TOTAL WATER INPUT TO SNOWPACK OR LITTER
$O             ,G(134)$
$I             ,G(9),G(5),G(56)$
C
      G(134) = G(9) + G(5) + G(56)
C
C
C---G(80)---------- TOTAL WEEKLY RAINFALL PLUS DRIP
$O             ,G(80)$
$I             ,G(134)$
$E             ,S3$
C
      G(80) = 7.0 * S3 ( 12 , G(134) )
C
C
C---G(2)---------- HEAT INPUT TO SNOWPACK DURING CONDENSATION
$O          ,G(2)$
$I          ,Z(5),G(160)$
$E          ,S1$
C
      G(2) = AMAX1 ( 0.0 , 80. * B(22) * ( S1 (Z(5)) - S1 (G(160)) ) )
C
C
C---G(170)--------- HEAT INPUT TO SNOWPACK DUE TO CONVECTION
$O             ,G(170)$
$I             ,Z(3),G(160)$
C
      G(170) = AMAX1 (  0.0  ,  80.0 * B(21) * ( Z(3) - G(160) )  )
C
C
C---G(114)--------- HEAT LOSS FROM SNOWPACK DUE TO SNOWFALL
$O             ,G(114)$
$I             ,Z(3),G(115)$
```

```
C
      G(114) = AMIN1 ( 0.0 , 0.005 * Z(3) * G(115) )
C
C
C---G(120)--------- NET HEAT TRANSFER FROM CANOPY TO SNOWPACK OR LITTER
C                   DUE TO LONGWAVE RADIATION
$O              ,G(120)$
$I              ,G(123),G(124),G(121),G(23)$
C
      G(120) = G(124) + ( 1.0 - G(23) ) * ( G(123) - G(121) )
C
C
C---G(117)--------- HEAT INPUT TO SNOWPACK DUE TO RAINFALL
$O              ,G(117)$
$I              ,Z(3),G(134)$
C
      G(117) = 0.01 * Z(3) * G(134)
C
C
C---G(127)--------- NET HEAT INPUT TO SNOWPACK
$O              ,G(127)$
$I              ,G(114),G(117),G(119),G(120),G(2),G(170)$
C
      G(127) = G(114) + G(117) + G(119) + G(120) + G(2) + G(170)
C
C
C---G(128)--------- NET INCREASE IN HEAT DEFICIT OF SNOWPACK
$O              ,G(128)$
$I              ,X(37),G(127),G(134),X(98),G(60)$
C
      T1 = G(127) + 0.8 * ( G(134) + X(98) )
      G(128) = AMAX1 ( -X(37) , -T1 )
      IF ( G(60) .LE. 1.0 )
     >   G(128) = AMIN1 ( 0.0 , G(128) )
C
C
C
C
C-----------------------------------------------------------------------
C     WATER - SNOW INPUT, FREEZE, AND MELT         [ MODULE 5 ]
C-----------------------------------------------------------------------
C
C
C
C---G(129)--------- TRANSFER FROM ICE TO FREE WATER IN SNOWPACK
$O              ,G(129)$
$I              ,G(60),G(127),X(37)$
C
      T1 = AMAX1 (  0.0  ,  ( G(127) - X(37) ) / 0.8  )
      G(129) = AMIN1 ( T1 , G(60) )
C
C
C---G(161)--------- NET DAILY FREEZING OF FREE WATER IN SNOWPACK
$O              ,G(161)$
$I              ,X(98),G(134),X(37),G(127),G(60)$
C
      G(161) = 0.0
      IF ( G(60) .LE. 0.0 )
     >   GO TO 16110
C     ELSE
```

```
         T1 = AMAX1 (  0.0  ,  ( X(37) - G(127) ) / 0.8  )
         G(161) = AMIN1 (  T1  ,  X(98) + G(134)  )
16110 CONTINUE
C
C
C---G(130)--------- FREE WATER HOLDING CAPACITY OF SNOWPACK
$O              ,G(130)$
$I              ,G(60)$
C
      G(130) = 0.04 * G(60)
C
C
C---G(74)---------- RAINFALL PASSING DIRECTLY TO FREE WATER IN SNOWPACK
$O              ,G(74)$
$I              ,G(9),G(60)$
C
      G(74) = G(9)
      IF ( G(60) .EQ. 0.0 )
     >   G(74) = 0.0
C
C
C---G(75)---------- DRIP FROM FOLIAR SURFACES TO FREE WATER IN SNOWPACK
C                   IN SNOWPACK
$O              ,G(75)$
$I              ,G(5),G(60)$
C
      G(75) = G(5)
      IF ( G(60) .EQ. 0.0 )
     >   G(75) = 0.0
C
C
C---G(76)---------- DRIP FROM EPIPHYTE AND BARK SURFACES TO FREE WATER
C                   IN SNOWPACK
$O              ,G(76)$
$I              ,G(56),G(60)$
C
      G(76) = G(56)
      IF ( G(60) .EQ. 0.0 )
     >   G(76) = 0.0
C
C
C---G(10)---------- WATER TRANSFER FROM SNOWPACK TO LITTER SURFACE
$O           ,G(10)$
$I              ,G(130),G(74),G(75),G(76),X(98),G(129),G(161),G(60)$
C
      G(10) = 0.0
      T1 = G(74) + G(75) + G(76) + G(129) + X(98) - G(161) - G(130)
      IF ( T1 .GT. 0.0 )
     >   G(10) = T1
      IF ( G(129) .EQ. G(60) )
     >   G(10) = G(10) + G(130)
C
C
C
C
C-----------------------------------------------------------------
C     WATER - LITTER MOISTURE DYNAMICS          [ MODULE 6 ]
C-----------------------------------------------------------------
C
C
```

```
C
C---G(70)---------- RAINFALL PASSING DIRECTLY TO LITTER SURFACE WATER
$O              ,G(70)$
$I              ,G(9),G(60)$
C
      G(70) = G(9)
      IF ( G(60) .GT. 0.0 )
     >   G(70) = 0.0
C
C
C---G(14)---------- PJTENTIAL EVAPORATION FROM LITTER
$O            ,G(14)$
$I            ,Z(5),Z(3),X(25)$
$E            ,S1$
C
      T1 = S1 ( X(25) ) - S1 ( Z(5) - Z(3) + X(25) )
      T2 = B(163) * B(155) * B(154) * B(159) / ( B(157) * B(156) )
      G(14) = AMAX1 ( 0.0 , T1 * T2 )
C
C
C---G(55)---------- WATER HOLDING CAPACITY OF LITTER
$O              ,G(55)$
$I              ,X(18),X(19),X(20)$
C
      G(55) = B(23) * ( B(74) * X(18) + X(19) + X(20) )
C
C
C---G(11)---------- WATER ENTERING LITTER
$O            ,G(11)$
$I            ,G(134),G(10),G(60)$
C
      G(11) = G(10)
      IF ( G(60) .LE. 0.001 )
     >   G(11) = G(10) + G(134)
C
C
C---G(15)---------- WATER TRANSFER FROM LITTER TO SCIL ROOTING ZONE
$O            ,G(15)$
$I            ,X(7),G(55),G(11),G(14)$
C
      G(15) = 0.0
      T1 = 1.0 - EXP ( -B(165) )
      T2 = ( G(11) - G(14) ) * ( 1.0 / T1 - 1.0 / B(165) )
      IF ( X(7) .GT. B(20) * G(55) )
     >   G(15) = T1 * ( T2 + X(7) - B(20) * G(55) )
C
C
C---G(22)---------- EVAPORATION FROM LITTER
$O            ,G(22)$
$I            ,G(55),X(7),G(11),G(14)$
C
      G(22) = 0.0
      T1 = ( B(11) - B(12) ) * G(55)
      IF ( X(7) .GE. B(12) * G(55) )
     >   G(22) = (  G(11) + X(7) - B(12) * G(55)   )  *
     >             (  1.0 - EXP ( -G(14) / T1 )      )
      IF ( X(7) .GT. B(11) * G(55) )
     >   G(22) = G(14)
C
C
```

```
C
C
C-----------------------------------------------------------------------
C     WATER - TRANSPIRATION                          [ MODULE 7 ]
C-----------------------------------------------------------------------
C
C
C
C---G(42)---------- PLANT MOISTURE STRESS (PMS)
$O               ,G(42)$
$I               ,Z(3),X(3)$
C
      G(42) = B(84)
      IF (  Z(3) .LT. B(79)   .OR.  X(3) .LE. B(5)   )
     >    GO TO 4210
C     ELSE
         G(42) = B(78)
         IF ( X(3) .LE. B(82) )
     >       G(42) = B(84) - B(85) * ( X(3) - B(5) )
 4210 CONTINUE
C
C
C---G(43)---------- NEW FOLIAGE STOMATAL RESISTANCE
$O               ,G(43)$
$I               ,G(42)$
C
      G(43) = B(86)
      IF ( G(42) .LE. B(87) )
     >    G(43) = B(88) * EXP ( B(89) * G(42) )
C
C
C---G(52)---------- STOMATAL RESISTANCE OF OLD FOLIAGE
$O               ,G(52)$
$I               ,G(43)$
C
      G(52) = B(60) * G(43)
C
C
C---G(1)---------- ONE-SIDED NEEDLE SURFACE AREA INDEX
$O             ,G(1)$
$I             ,G(61)$
C
      G(1) = B(7) * G(61)
C
C
C---G(101)--------- CANOPY RESISTANCE
$O               ,G(101)$
$I               ,G(43),X(10),G(52),X(11),G(61)$
C
      T1 = G(43) * X(10) + G(52) * X(11)
      G(101) = 100.0 * T1 / G(61)
C
C
C---G(20)---------- TRANSPIRATION RATE
$O          ,G(20)$
$I          ,G(17),G(169),Z(4),G(99),G(100),G(101),G(1),X(1),G(3),G(5)$
$I          ,G(7),X(3)$
C
      T1 = B(159) * ( G(17) * G(169) * B(164) * Z(4) + G(99) / G(100) )
      T2 = G(17) + B(158) * ( 1.0 + G(101) / ( 2.0 * G(1) * G(100) ) )
```

```
      G(20) = T1 / ( B(157) * T2 )
      IF ( X(1) + G(3) - G(5) - G(7) .GE. B(171) )
     >   G(20) = 0.0
      IF ( X(3) .LT. B(5) )
     >   G(20) = 0.0
C
C
C
C
C-----------------------------------------------------------------------
C     SOIL, SUBSOIL, AND GROUND WATER              [ MODULE 8 ]
C-----------------------------------------------------------------------
C
C
C
C---G(12)---------- WATER TRANSFER FROM SOIL ROOTING ZONE TO SUBSOIL
$O          ,G(12)$
$I          ,G(15),G(20),X(3)$
C
      T1 = 1.0 - EXP ( -B(9) )
      T2 = ( G(15) - G(20) ) * ( 1.0 / T1 - 1.0 / B(9) )
      G(12) = AMAX1 (  0.0  ,  T1 * ( T2 + X(3) - B(13) )  )
C
C
C---G(19)---------- WATER TRANSFER FROM SUBSOIL TO GROUNDWATER
$O          ,G(19)$
$I          ,G(12),X(4)$
C
      T1 = 1.0 - EXP ( -B(10) )
      T2 = G(12) * ( 1.0 / T1 - 1.0 / B(10) )
      G(19) = AMAX1 (  0.0  ,  T1 * ( T2 + X(4) - B(14) )  )
C
C
C---G(18)---------- OUTFLOW FROM GROUND WATER
$O          ,G(18)$
$I          ,X(5)$
C
      G(18) = AMAX1 ( 0.0 , X(5) - B(16) )
C
C
C
C
C-----------------------------------------------------------------------
C     LITTER AND SOIL TEMPERATURES                 [ MODULE 9 ]
C-----------------------------------------------------------------------
C
C                 ZERO ALL G-S IF THIS IS DURING WEEK.
C
      IF ( KT .EQ. 0 )
     >   GO TO 90100
C
      G(67) = 0.0
      G(68) = 0.0
C
      GO TO 90110
C
90100 CONTINUE
C
C
C---G(67)---------- CHANGE IN LITTER TEMPERATURE
```

```
$O              ,G(67)$
$I              ,G(80),G(48),X(25),X(2)$
C
      T1 = B(92) * ( 1.0 + G(80) / B(93) )
      T2 = AMIN1 ( 1.0 , T1 )
      G(67) = T2 * ( G(48) - X(25) )
      IF ( X(2) .GT. 100.0 )
     >   G(67) = 3.0 - X(25)
C
C
C---G(68)---------- CHANGE IN SOIL TEMPERATURE
$O              ,G(68)$
$I              ,G(80),X(25),X(26)$
C
      T1 = B(95)
      G(68) = ( X(25) - X(26) ) * AMIN1 ( 1.0 , T1 )
C
C
90110 CONTINUE
C
C
C
C-----------------------------------------------------------------------
C     WEEKLY AVERAGES FROM OTHER MODULES          [ MODULE 10 ]
C             (CALCULATED DAILY)
C-----------------------------------------------------------------------
C
C
C
C---G(51)---------- WEEKLY AVERAGE SOIL TEMPERATURE
$O              ,G(51)$
$I              ,X(26)$
C
      G(51) = X(26)
C
C
C---G(49)---------- AVERAGE WEEKLY STOMATAL RESISTANCE OF NEW FOLIAGE
$O              ,G(49)$
$I              ,G(43)$
$E              ,S3$
C
      G(49) = S3 ( 1 , G(43) )
C
C
C---G(48)---------- AVERAGE WEEKLY 24-HOUR AIR TEMPERATURE
$O              ,G(48)$
$I              ,Z(3)$
$E              ,S3$
C
      G(48) = S3 ( 6 , Z(3) )
C
C
C---G(58)---------- AVERAGE WEEKLY STOMATAL RESISTANCE OF OLD FOLIAGE
$O              ,G(58)$
$I              ,G(52)$
$E              ,S3$
C
      G(58) = S3 ( 7 , G(52) )
C
C
```

```
C---G(107)--------- AVERAGE WEEKLY DAYTIME AIR TEMPERATURE
$O              ,G(107)$
$I              ,Z(6)$
$E              ,S3$
C
      G(107) = S3 ( 4 , Z(6) )
C
C
C---G(108)--------- AVERAGE WEEKLY NIGHTTIME AIR TEMPERATURE
$O              ,G(108)$
$I              ,Z(7)$
$E              ,S3$
C
      G(108) = S3 ( 5 , Z(7) )
C
C
C---G(109)--------- AVERAGE WEEKLY PHOTOSYNTHETICALLY ACTIVE RADIATION
$O              ,G(109)$
$I              ,Z(2)$
$E              ,S3$
C
      G(109) = B(183) * S3 ( 2 , Z(2) )
C
C
C---G(110)--------- AVERAGE WEEKLY DAYLENGTH
$O              ,G(110)$
$I              ,Z(4)$
$E              ,S3$
C
      G(110) = S3 ( 3 , Z(4) )
C
C
C
C
C-----------------------------------------------------------------------
C     PRIMARY PRODUCTION - PHOTOSYNTHESIS         [ MODULE 11 ]
C            (CALCULATED WEEKLY)
C-----------------------------------------------------------------------
C
C                 ZERO ALL G-S IF THIS IS DURING WEEK.
C
      IF ( KT .EQ. 0 )
     >   GO TO 91200
C
      G(24)  = 0.0
      G(25)  = 0.0
      G(29)  = 0.0
      G(30)  = 0.0
      G(102) = 0.0
C
      GO TO 91210
C
91200 CONTINUE
C
C
C---G(102)--------- EFFECT OF TEMPERATURE ON PHOTOSYNTHESIS
$O              ,G(102)$
$I              ,G(107)$
$E              ,S2$
C
```

```
      G(102) = S2 ( G(107) , 0.0 , B(176) , B(177) )
C
C
C---G(24)---------- NET NEW FOLIAGE PHOTOSYNTHESIS
$O          ,G(24)$
$I          ,G(102),G(109),X(10),G(61),G(110),G(49)$
C
      T1 = B(35) * G(61)
      T2 = B(34) + G(109) * EXP ( -T1 )
      T3 = ALOG (  T2 / ( B(34) + G(109) )  )
      G(24) = -B(32) * B(33) * G(110) * G(102) * X(10) * T3 /
     >         ( T1 * G(49) )
C
C
C---G(25)---------- NEW FOLIAGE NIGHTTIME RESPIRATION
$O          ,G(25)$
$I          ,G(108),G(110),X(10)$
C
      T1 = EXP ( B(145) * G(108) )
      G(25) = B(26) * X(10) * T1 * ( 1.0 - G(110) )
C
C
C---G(30)---------- OLD FOLIAGE NIGHTTIME RESPIRATION
$O          ,G(30)$
$I          ,G(108),G(110),X(11),X(12)$
C
      T1 = EXP ( B(145) * G(108) )
      G(30) = B(27) * B(26) * X(11) * X(12) * T1 * ( 1.0 - G(110) ) /
     >         ( B(44) + X(12) )
C
C
C---G(29)---------- NET OLD FOLIAGE PHOTOSYNTHESIS
$O          ,G(29)$
$I          ,G(109),G(61),X(11),G(110),G(102),G(58)$
C
      T1 = B(35) * G(61)
      T2 = (  B(42) + G(109) * EXP ( -T1 )  )  /
     >     (  B(42) + G(109)  )
      G(29) = -B(32) * B(41) * G(110) * G(102) * X(11) * ALOG ( T2 ) /
     >         ( T1 * G(58) )
C
C
91210 CONTINUE
C
C
C
C-------------------------------------------------------------------------
C     BUD DYNAMICS AND FOLIAR GROWTH LIMITS      [ MODULE 12 ]
C             (CALCULATED WEEKLY)
C-------------------------------------------------------------------------
C
C                 ZERO ALL G-S IF THIS IS DURING WEEK
C
      IF ( KT .EQ. 0 )
     >   GO TO 91300
C
      G(33) = 0.0
      G(35) = 0.0
      G(38) = 0.0
      G(39) = 0.0
```

```
      G(44) = 0.0
      G(79) = 0.0
      G(95) = 0.0
      G(106)= 0.0
C
      GO TO 91310
C
91300 CONTINUE
C
C
C---G(106)--------- PHENOLOGY OF TREE GROWTH
$O                 ,G(106)$
$E                 ,TIMER$
C
      G(106) = 1.0
      IF ( KTW .LT. M(2) .OR. KTW .GE. M(3) )
     >   G(106) = 0.0
C
C
C---G(39)---------- TEMPERATURE EFFECT ON GROWTH PROCESSES
$O                 ,G(39)$
$I                 ,G(48)$
$E                 ,S2$
C
      G(39) = B(36) * S2 ( G(48) , 0.0 , B(76) , B(77) )
C
C
C---G(95)---------- BUD CONSUMPTION BY INSECTS
$O                 ,G(95)$
$I                 ,X(16),G(39)$
C
      G(95) = B(59) * X(16) * G(39)
C
C
C---G(33)---------- BUD GROWTH
$O                 ,G(33)$
$I                 ,G(39),G(106)$
C
      G(33) = B(31) * G(39)
      IF ( G(106) .EQ. 0.0 )
     >   G(33) = 0.0
C
C
C---G(38)---------- NEW FOLIAGE CONSUMPTION BY INSECTS
$O                 ,G(38)$
$I                 ,G(39),X(10)$
C
      G(38) = B(56) * X(10) * G(39)
C
C
C---G(79)---------- CARBON TRANSFER FROM BUDS TO NEW FOLIAGE
$O                 ,G(79)$
$E                 ,TIMER$
$I                 ,X(16),G(38)$
C
      G(79) = 0.0
      IF ( KTW .EQ. M(1) )
     >   G(79) = X(16) + G(38)
C
C
```

```
C---G(44)---------- INCREMENT TO POTENTIAL NEW FOLIAGE
$D              ,G(44)$
$I              ,G(38),X(38),G(106),X(16)$
$E              ,TIMER,S6$
C
      G(44) = - AMIN1 ( X(38) , G(38) / B(37) +
     >                 S6 ( B(166), B(169), B(167) * X(38) ) )
      IF ( KTW .EQ. M(1) )
     >   G(44) = X(16) * ( 1.0 - B(167) )
      IF ( G(106) .EQ. 0.0 )
     >   G(44) = -X(38)
C
C
91310 CONTINUE
C
C
C
C-----------------------------------------------------------------------
C     STEM, BRANCH, AND ROOT RESPIRATION AND      [ MODULE 13 ]
C          GROWTH (CALCULATED WEEKLY)
C-----------------------------------------------------------------------
C               ZERO ALL G-S IF THIS IS DURING WEEK
C
      IF ( KT .EQ. 0 )
     >   GO TO 91400
C
      G(31)  = 0.0
      G(36)  = 0.0
      G(37)  = 0.0
      G(53)  = 0.0
      G(138) = 0.0
      G(139) = 0.0
      G(140) = 0.0
C
      GO TO 91410
C
91400 CONTINUE
C
C
C---G(35)--------- CARBON TRANSFER TO STEMS AND BRANCHES
$D              ,G(35)$
$I              ,G(106),G(39),X(12)$
C
      G(35) = 0.0
      IF ( G(106) .GT. 0.0 )
     >   G(35) = B(45) * G(39) * X(12) / ( X(12) + B(46) )
C
C
C---G(53)---------- EFFECT OF SOIL TEMPERATURE ON SOIL PROCESSES
$D              ,G(53)$
$I              ,G(51)$
$E              ,S2$
C
      G(53) = B(54) * S2 ( G(51) , 0.0 , B(178) , B(179) )
C
C
C---G(36)---------- CARBON TRANSFER TO LARGE ROOTS
$D              ,G(36)$
$I              ,G(53),X(12)$
C
```

```
      G(36) = B(47) * G(53) * X(12) / ( X(12) + B(48) )
C
C
C---G(37)---------- CARBON TRANSFER TO FINE ROOTS
$O                ,G(37)$
$I                ,G(53),X(12)$
C
      G(37) = B(49) * G(53) * X(12) / ( X(12) + B(50) )
C
C
C---G(138)--------- STEM AND BRANCH RESPIRATION
$O                ,G(138)$
$I                ,G(48),X(12)$
$E                ,TIMER$
C
      G(138) = B(28) * X(12) * EXP ( B(141) * G(48) ) /
     >          ( X(12) + B(46) )
C
C
C---G(139)--------- LARGE ROOT RESPIRATION
$O                ,G(139)$
$I                ,G(51),X(12)$
$E                ,TIMER$
C
      G(139) = B(29) * X(12) * EXP ( B(141) * G(51) ) /
     >          ( X(12) + B(48) )
C
C
C---G(140)--------- FINE ROOT RESPIRATION
$O                ,G(140)$
$I                ,G(51),X(12),X(15)$
$E                ,TIMER$
C
      G(140) = B(30) * X(12) * X(15) * EXP ( B(141) * G(51) ) /
     >          ( X(12) + B(50) )
C
C
C---G(31)---------- TOTAL RESPIRATION LOSS FROM GROWTH CARBOHYDRATE
C                   POOL
$O            ,G(31)$
$I            ,G(139),G(138),G(140),G(30)$
C
      G(31) = G(139) + G(138) + G(140) + G(30)
C
C
91410 CONTINUE
C
C
C
C---------------------------------------------------------------------
C     FOLIAR GROWTH AND CH2O POOL DYNAMICS         [ MODULE 14 ]
C            (CALCULATED WEEKLY)
C---------------------------------------------------------------------
C
C                 ZERO ALL G-S IF THIS IS DURING WEEK.
C
      IF ( KT .EQ. 0 )
     >   GO TO 91500
C
      G(26) = 0.0
```

```
      G(27) = 0.0
      G(28) = 0.0
      G(32) = 0.0
      G(34) = 0.0
      G(45) = 0.0
      G(46) = 0.0
      G(47) = 0.0
C
      GO TO 91510
C
91500 CONTINUE
C
C
C---G(46)---------- NEW FOLIAGE GROWTH DEMAND
$O              ,G(46)$
$I              ,X(38),G(44),X(10),G(39)$
C
      T1 = B(37) * ( X(38) + G(44) ) - X(10)
      G(46) = B(71) * G(39) * AMAX1 ( 0.0 , B(38) * T1 )
C
C
C---G(45)---------- PORTION OF GROWTH CARBOHYDRATE POOL AVAILABLE FOR
C                   FOLIAR RESPIRATION AND GROWTH
$O              ,G(45)$
$I              ,X(12)$
C
      G(45) = B(39) * X(12) / ( B(40) + X(12) )
C
C
C---G(47)---------- SURPLUS OR DEFICIT OF NEW FOLIAGE PHOTOSYNTHATE
C                   AFTER NEW FOLIAGE RESPIRATION IS SATISFIED
$O              ,G(47)$
$I              ,G(24),G(25)$
C
      G(47) = G(24) - G(25)
C
C
C---G(27)---------- TRANSFER OF CARBON FROM NEW FOLIAGE TO NEW FOLIAGE
C                   CARBOHYDRATE POOL
$O          ,G(27)$
$I          ,G(45),G(47)$
C
      G(27) = 0.0
      T1 = G(45) + G(47)
      IF ( T1 .LT. 0.0 )
     >   G(27) = -T1
C
C
C---G(32)---------- TRANSFER OF CARBON FROM GROWTH CARBOHYDRATE POOL
C                   TO NEW FOLIAGE POOL TO MEET FOLIAR RESPIRATION AND
C                   GROWTH DEMANDS
$O              ,G(32)$
$I              ,G(47),G(46),G(45)$
C
      IF ( G(47) .GT. 0.0 )
     >   GO TO 3210
C     ELSE
         G(32) = G(46)
         T1 = G(45) + G(47)
         IF ( T1 .LE. G(46) )
```

```
     >        G(32) = T1
          IF ( T1 .LE. 0.0 )
     >        G(32) = G(45)
          GO TO 3220
 3210 CONTINUE
          G(32) = G(45)
          T2 = G(46) - G(47)
          IF ( T2 .LE. G(45) )
     >        G(32) = T2
          IF ( T2 .LE. 0.0 )
     >        G(32) = 0.0
 3220 CONTINUE
C
C
C---G(26)---------- TRANSFER OF CARBON TO NEW FOLIAGE FROM NEW FOLIAGE
C                   CARBOHYDRATE POOL
$C           ,G(26)$
$I           ,G(45),G(47),G(46)$
C
      G(26) = G(46)
      T1 = G(45) + G(47)
      IF ( T1 .LT. G(46) )
     >   G(26) = T1
      IF ( T1 .LE. 0.0 )
     >   G(26) = 0.0
C
C
C---G(28)---------- TRANSFER OF SURPLUS CARBON FROM NEW FOLIAGE
C                   CARBOHYDRATE POOL TO GROWTH CARBOHYDRATE POOL
$C           ,G(28)$
$I           ,G(47),G(45),G(46)$
C
      G(28) = 0.0
      IF ( G(47) + G(45) .GE. 0.0 )
     >   G(28) = G(47)
      IF ( G(47) .GE. 0.0 )
     >   G(28) = AMAX1 (  0.0 , G(47) - G(46)  )
C
C
C---G(34)---------- MATURATION OF NEW FOLIAGE
$C              ,G(34)$
$I              ,X(10),G(26),G(27),G(38)$
$E              ,TIMER$
C
      G(34) = 0.0
      IF ( KTW .EQ. M(4) )
     >   G(34) = X(10) + G(26) - G(27) - G(38)
C
C
91510 CONTINUE
C
C
C
C----------------------------------------------------------------------
C     MORTALITY AND LEAF FALL (CALCULATED WEEKLY)[ MODULE 15 ]
C----------------------------------------------------------------------
C
C                ZERO ALL G-S IF THIS IS DURING WEEK
C
      IF ( KT .EQ. 0 )
```

```
      >   GO TO 91600
C
       G(40)  = 0.C
       G(62)  = 0.0
       G(82)  = 0.0
       G(86)  = 0.0
       G(87)  = 0.C
       G(92)  = 0.0
       G(93)  = 0.C
       G(97)  = 0.0
       G(135) = 0.0
       G(136) = 0.0
C
       GO TO 91610
C
91600 CONTINUE
C
C
C---G(93)---------- ACUTE OLD FOLIAGE DEFOLIATION
$O              ,G(93)$
$I              ,X(11)$
$E              ,S6$
C
       G(93) = S6 ( B(185) , B(186) , B(184) * X(11) )
C
C
C---G(135)---------- CARBON TRANSFER FROM NEW FOLIAGE TO LEAF LITTER
C                                 DUE TO ACUTE DEFOLIATION
$O              ,G(135)$
$I              ,X(10)$
$E              ,S6$
C
       G(135) = 0.5 * S6 ( B(166) , B(169) , B(167) * X(10) )
C
C
C---G(136)---------- CARBON TRANSFER FROM OLD FOLIAGE TO FINE LITTER DUE
C                   TO ACUTE DEFOLIATION
$O              ,G(136)$
$I              ,G(93)$
C
       G(136) = 0.5 * G(93)
C
C
C---G(40)----------- LEAF FALL RATE
$O              ,G(40)$
$I              ,X(11),G(93)$
$E              ,TIMER,S2$
C
       T2 = KTW
       T3 = FLOAT ( M(5) )
       IF ( KTW .GT. M(5) )
      >   GO TO 4010
C      ELSE
          T1 = B(43) * S2 ( T2 , T3-52.0 , T3 , B(91) )
          GO TO 4020
 4010 CONTINUE
          T1 = B(43) * S2 ( T2 , T3 , T3+52.0 , B(91) )
C
 4020 G(40) = 0.5 * G(93) + X(11) * ( B(182) + T1 )
C
```

```
C
C---G(82)---------- INSECT FRASS INPUT TO FINE LITTER
$O                 ,G(82)$
$I                 ,X(17)$
C
      G(82) = B(75) * X(17)
C
C
C---G(86)---------- LARGE ROOT MORTALITY
$O                 ,G(86)$
$I                 ,X(14)$
C
      G(86) = B(52) * X(14)
C
C
C---G(87)---------- FINE ROOT MORTALITY
$O                 ,G(87)$
$I                 ,X(15),G(42)$
C
      G(87) = B(53) * X(15) * G(42) / B(76)
C
C
C---G(92)---------- CARBON TRANSFER FROM STEMS PLUS BRANCHES TO WOODY
C                   LITTER
$O                 ,G(92)$
$I                 ,X(13)$
C
      G(92) = B(150) * B(51) * X(13)
C
C
C---G(62)---------- CARBON TRANSFER FROM STEMS PLUS BRANCHES TO
C                   LOG LITTER
$O                 ,G(62)$
$I                 ,X(13)$
C
      G(62) = B(51) * X(13) * ( 1.0 - B(150) )
C
C
C---G(97)---------- INPUT TO FINE LITTER FROM MICROPARTICULATE MATTER
C                   AND CARBON DISSOLVED IN PRECIPITATION
$O                 ,G(97)$
C
      G(97) = B(152)
C
C
91610 CONTINUE
C
C
C
C------------------------------------------------------------------------
C     OLD FOLIAGE CONSUMPTION (CALCULATED WEEKLY)[ MODULE 16 ]
C------------------------------------------------------------------------
C
C                ZERO ALL G-S IF THIS IS DURING WEEK.
C
      IF ( KT .EQ. 0 )
     > GO TO 91700
C
      G(90) = 0.0
      G(94) = 0.0
```

```
C
      GO TO 91710
C
91700 CONTINUE
C
C
C---G(94)---------- CONSUMPTION OF GROWTH CH2O POOL BY INSECTS
$O                 ,G(94)$
$I                 ,X(12),G(39)$
C
      G(94) = B(58) * X(12) * G(39)
C
C
C---G(90)---------- OLD FOLIAGE CONSUMPTION BY INSECTS
$O                 ,G(90)$
$I                 ,X(11),G(39)$
C
      G(90) = B(57) * X(11) * G(39)
C
C
91710 CONTINUE
C
C
C
C-----------------------------------------------------------------
C     LITTER DECOMPOSITION (CALCULATED WEEKLY)    [ MODULE 17 ]
C-----------------------------------------------------------------
C
C                 ZERO ALL G-S IF THIS IS DURING WEEK.
C
      IF ( KT .EQ. 0 )
     >   GO TO 91800
C
      G(69)  = 0.0
      G(77)  = 0.0
      G(81)  = 0.0
      G(83)  = 0.0
      G(84)  = 0.0
      G(98)  = 0.0
      G(103) = 0.0
      G(104) = 0.0
      G(105) = 0.0
      G(111) = 0.0
      G(112) = 0.0
      G(113) = 0.0
      G(116) = 0.0
      G(125) = 0.0
C
      GO TO 91810
C
91800 CONTINUE
C
C
C---G(77)---------- EFFECT OF TEMPERATURE ON LITTER PROCESSES
$O                 ,G(77)$
$I                 ,G(41)$
$E                 ,S2$
C
      G(77) = B(24) * S2 ( G(41) , 0.0 , B(180) , B(181) )
C
```

```
C
C---G(69)---------- EFFECT OF TEMPRATURE AND MOISTURE ON LITTER
C                   PROCESSES
$O              ,G(69)$
$I              ,X(7),G(55),G(77)$
C
      G(69) = B(94) * X(7) * G(77)
      IF ( X(7) .GE. G(55) )
     >   G(69) = B(94) * G(55) * G(77)
C
C
C---G(105)--------- LOG LITTER DECOMPOSITION RATE
$O              ,G(105)$
$I              ,X(9),G(77)$
C
      G(105) = B(146) * X(9) * G(77)
C
C
C---G(112)--------- CARBON LOSS FROM LOGS DUE TO FRAGMENTATION
$O              ,G(112)$
$I              ,G(105)$
C
      G(112) = G(105) * B(147)
C
C
C---G(113)--------- CARBON LOSS FROM LOGS DUE TO RESPIRATION
$O              ,G(113)$
$I              ,G(105)$
C
      G(113) = G(105) * ( 1.0 - B(147) )
C
C
C---G(83)---------- WOODY LITTER DECOMPOSITION RATE
$O              ,G(83)$
$I              ,G(69),X(18)$
C
      G(83) = B(61) * G(69) * X(18)
C
C
C---G(104)--------- CARBON LOSS FROM WOODY LITTER DUE TO FRAGMENTATION
$O              ,G(104)$
$I              ,G(83)$
C
      G(104) = B(148) * G(83)
C
C
C---G(111)--------- CARBON LOSS FROM WOODY LITTER DUE TO RESPIRATION
$O              ,G(111)$
$I              ,G(83)$
C
      G(111) = G(83) * ( 1.0 - B(148) )
C
C
C---G(81)---------- FOLIAGE LITTER DECOMPOSTION RATE
$O              ,G(81)$
$I              ,G(69),X(19)$
C
      G(81) = B(62) * G(69) * X(19)
C
C
```

```
C---G(98)---------- CARBON LOSS FROM FOLIAGE LITTER DUE TO FRAGMENTATION
$O              ,G(98)$
$I              ,G(81)$
C
      G(98) = B(149) * G(81)
C
C
C---G(103)--------- CARBON LOSS FROM FOLIAGE LITTER DUE TO RESPIRATION
$O              ,G(103)$
$I              ,G(81)$
C
      G(103) = G(81) * ( 1.0 - B(149) )
C
C
C---G(84)---------- FINE LITTER DECOMPOSITION RATE
$O              ,G(84)$
$I              ,G(69),X(20)$
C
      G(84) = B(63) * G(69) * X(20)
C
C
C---G(116)--------- INCORPORATION OF FINE LITTER INTO ROOTING ZONE
C                   ORGANIC MATTER
$O              ,G(116)$
$I              ,G(84)$
C
      G(116) = G(84) * B(64)
C
C
C---G(125)--------- CARBON LOSS FROM FINE LITTER DUE TO RESPIRATION
$O              ,G(125)$
$I              ,G(84)$
C
      G(125) = G(84) * ( 1.0 - B(64) )
C
C
91810 CONTINUE
C
C
C
C-----------------------------------------------------------------
C     SOIL AND SUBSOIL DECOMPOSITION              [ MODULE 18 ]
C          (CALCULATED WEEKLY)
C-----------------------------------------------------------------
C
C               ZERO ALL G-S IF THIS IS DURING WEEK.
C
      IF ( KT .EQ. 0 )
     >   GO TO 91900
C
      G(50)  = 0.0
      G(85)  = 0.0
      G(88)  = 0.0
      G(126) = 0.0
      G(131) = 0.0
      G(132) = 0.0
      G(133) = 0.0
C
      GO TO 91910
C
```

```
91900 CONTINUE
C
C
C---G(50)---------- EFFECT OF MOISTURE AND TEMPERATURE ON ROOTING ZONE
C                  PROCESS
$O             ,G(50)$
$I             ,X(3),G(53)$
C
      G(50) = X(3) * G(53) / B(67)
C
C
C---G(85)---------- DEAD ROOT DECOMPOSITION RATE
$O             ,G(85)$
$I             ,G(50),X(62)$
C
      G(85) = B(68) * G(50) * X(62)
C
C
C---G(126)--------- CARBON LOSS FROM DEAD ROOTS DUE TO FRAGMENTATION
$O             ,G(126)$
$I             ,G(85)$
C
      G(126) = G(85) * B(69)
C
C
C---G(131)--------- CARBON LOSS FROM DEAD ROOTS DUE TO RESPIRATION
$O             ,G(131)$
$I             ,G(85)$
C
      G(131) = G(85) * ( 1.0 - B(69) )
C
C
C---G(88)---------- ROOT ZONE ORGANIC MATTER DCOMPOSITION RATE
$O             ,G(88)$
$I             ,G(50),X(21)$
C
      G(88) = B(65) * G(50) * X(21)
C
C
C---G(132)--------- CARBON TRANSFER FROM SOIL ROOTING ZONE TO SUBSOIL
$O             ,G(132)$
$I             ,G(88)$
C
      G(132) = G(88) * B(66)
C
C
C---G(133)--------- CARBON LOSS FROM ROOTING ZONE DUE TO RESPIRATION
$O             ,G(133)$
$I             ,G(88)$
C
      G(133) = G(88) * ( 1.0 - B(66) )
C
C
91910 CONTINUE
C
C
      RETURN
      END
C
C
```

```
C***********************************************************************
C     FLOWS                          FLOWS                           FLOWS
C***********************************************************************
C
C                              DRIP FROM FOLIAR SURFACES TC LITTER SURFACE
C                              WATER
(1,6).    F = G(71)
C                              DRIP FROM FOLIAR SURFACES TC FREE WATER IN SNOW
C                              PACK
(1,98).   F = G(75)
C                              EVAPORATION FROM FOLIAR SURFACES
(1,99).   F = G(7)
C                              TRANSFER FROM ICE TO FREE WATER IN SNOWPACK
(2,98).   F = G(129)
C                              WATER TRANSPIRATION FROM SOIL ROOTING ZONE TO
C                              SUBSOIL
(3,4).    F = G(12)
C                              TRANSPIRATION FROM SCIL ROOTING ZONE
(3,99).   F = G(20)
C                              WATER TRANSFER FROM SUBSOIL TO GROUNDWATER
(4,5).    F = G(19)
C                              OUTFLOW FROM GROUNDWATER
(5,99).   F = G(18)
C                              WATER ENTERING LITTER
(6,7).    F = G(11)
C                              WATER TRANSFER FROM LITTER TO SOIL ROOTING ZONE
(7,3).    F = G(15)
C                              EVAPORATION FROM LITTER
(7,99).   F = G(22)
C                              DRIP FROM EPIPHYTE AND BARK SURFACES TO LITTER
C                              SURFACE WATER
(8,6).    F = G(72)
C                              DRIP FROM EPIPHYTE AND BARK SURFACES TO FREE
C                              WATER IN SNOWPACK
(8,98).   F = G(76)
C                              EVAPORATICN FROM EPIPHYTE AND BARK SURFACES
(8,99).   F = G(8)
C                              CARBON LOSS FROM LOGS DUE TC FRAGMENTATION
(9,20).   F = G(112)
C                              CARBON LOSS FROM LOGS DUE TC RESPIRATION
(9,99).   F = G(113)
C                              MATURATION OF NEW FOLIAGE
(10,11).  F = G(34)
C                              INSECT CONSUMPTION OF NEW LEAVES
(10,17).  F = G(38)
C                              NEW FOLIAGE DEFOLIATION TO LEAF LITTER
(10,19).  F = G(135)
C                              NEW FOLIAGE DEFOLIATION TO FINE LITTER
(10,20).  F = G(135)
C                              TRANSFER OF CARBON FROM NEW FCLIAGE TO NEW
C                              FOLIAGE CARBOHYDRATE POOL
(10,64).  F = G(27)
C                              OLD FOLIAGE CONSUMPTICN BY INSECTS
(11,17).  F = G(90)
C                              LEAF FALL RATE
(11,19).  F = G(40)
C                              CARBON TRANSFER FROM OLD FOLIAGE TO FINE LITTER
C                              DUE TO ACUE DEFOLIATICN
(11,20).  F = G(136)
C                              CARBON TRANSFER TO STEMS AND BRANCHES
```

```
(12,13). F = G(35)
C                   CARBON TRANSFER TO LARGE ROOTS
(12,14). F = G(36)
C                   CARBON TRANSFER TO FINE ROOTS
(12,15). F = G(37)
C                   BUD GROWTH
(12,16). F = G(33)
C                   CONSUMPTION OF GROWTH CH2O POOL BY INSECTS
(12,17). F = G(94)
C                   TRANSFER OF CARBON FROM GROWTH CARBOHYDRATE POOL
C                   TO NEW FOLIAGE POOL TO MEET FOLIAR RESPIRATION
C                   AND GROWTH DEMANDS
(12,64). F = G(32)
C                   TOTAL CARBOHYDRATE POOL RESPIRATION LOSS
(12,99). F = G(31)
C                   BOLE FALL
(13,9).  F = G(62)
C                   CARBON TRANSFER FROM STEMS AND BRANCHES
C                   TO WOODY LITTER
(13,18). F = G(92)
C                   LARGE ROOT MORTALITY
(14,62). F = G(86)
C                   FINE ROOT MORTALITY
(15,62). F = G(87)
C                   TRANSFER OF CARBON FROM BUDS TO NEW FOLIAGE
(16,10). F = G(79)
C                   BUD CONSUMPTION BY INSECTS
(16,17). F = G(95)
C                   INSECT FRASS INPUT TO FINE LITTER
(17,20). F = G(82)
C                   CARBON LOSS FROM WOODY LITTER DUE TO
C                   FRAGMENTATION
(18,20). F = G(104)
C                   CARBON LOSS FROM WOODY LITTER DUE TO
C                   RESPIRATION
(18,99). F = G(111)
C                   CARBON LOSS FROM FOLIAGE LITTER DUE TO FRAG-
C                   MENTATION
(19,20). F = G(98)
C                   CARBON LOSS FROM FOLIAGE LITTER DUE TO
C                   RESPIRATION
(19,99). F = G(103)
C                   INCORPORATION OF FINE LITTER INTO ROOTING ZONE
C                   ORGANIC MATTER
(20,21). F = G(116)
C                   CARBON LOSS FROM FINE LITTER DUE TO RESPIRATION
(20,99). F = G(125)
C                   CARBON TRANSFER FROM SOIL ROOTING ZONE TO
C                   SUBSOIL
(21,22). F = G(132)
C                   CARBON LOSS FROM ROOTING ZONE DUE TO RESPIRATION
(21,99). F = G(133)
C                   CARBON LOSS FROM DEAD ROOTS DUE TO FRAGMENTATION
(62,21). F = G(126)
C                   CARBON LOSS FROM DEAD ROOTS DUE TO RESPIRATION
(62,99). F = G(131)
C                   TRANSFER OF CARBON TO NEW FOLIAGE FROM NEW
C                   FOLIAGE CARBOHYDRATE POOL
(64,10). F = G(26)
C                   TRANSFER OF SURPLUS CARBON FROM NEW FOLIAGE
```

```
C                             CARBOHYDRATE POOL TO GROWTH CARBOHYDRATE POOL
(64,12). F = G(28)
C                             NEW FOLIAGE NIGHTTIME RESPIRATION
(64,99). F = G(25)
C                             NET DAILY FREEZING OF FREE WATER IN SNOWPACK
(98,2).  F = G(161)
C                             WATER TRANSFER FROM SNOWPACK TO LITTER SURFACE
(98,6).  F = G(10)
C                             RAIN INPUT TO FOLIAR SURFACES
(99,1).  F = G(3)
C                             PRECIPITATION AS SNOW
(99,2).  F = G(115)
C                             RAINFALL PASSING DIRECTLY TO LITTER SURFACE
C                             WATER
(99,6).  F = G(70)
C                             RAIN INPUT TO EPIPHYTE AND BARK SURFACES
(99,8).  F = G(4)
C                             NET OLD FOLIAGE PHOTOSYNTHESIS
(99,12). F = G(29)
C                             INPUT TO FINE LITTER FROM MICROPARTICULATE
C                             MATTER AND CARBON DISSOLVED IN PRECIPITATION
(99,20). F = G(97)
C                             CHANGE IN LITTER TEMPERATURE
(99,25). F = G(67)
C                             CHANGE IN SOIL TEMPERATURE
(99,26). F = G(68)
C                             CHANGE IN CALORIE DEFICIT OF SNOW
(99,37). F = G(128)
C                             ACUTE OLD FOLIAGE DEFOLIATION
(99,38). F = G(44)
C                             NET NEW FOLIAGE PHOTOSYNTHESIS
(99,64). F = G(24)
C                             RAINFALL PASSING DIRECTLY TO FREE WATER IN SNOW
C                             PACK
(99,98). F = G(74)
C
C
C***********************************************************************
C
      SUBROUTINE TIMER
C
C     KWK - WEEK NUMBER,REFERRED TO JAN. 1 OF STARTING YEAR
C     KTW - ACTUAL WEEK OF THE YEAR
C       K - TIME (IN DAYS) + 1
C      KP - TSTART
C     KT1 - NO. DAYS SINCE START OF RUN
C      KT - DAY OF THE WEEK, REFERRED TO START OF RUN
C
      K = TIME + 1.0
      KWK = K / 7
C
      KTW = MOD ( KWK , 52 )
      KP = TSTART
      KT1 = K - KP
      KT = MOD ( KT1 , 7 )
C
      RETURN
      END
C
C***********************************************************************
```

```
C
      SUBROUTINE ZUP
C
C                 THIS ROUTINE UPDATES ALL DRIVING VARIABLES.
C
C                        Z(1)    TOTAL PRECIPITATION
C                        Z(2)    AVERAGE RADIATION (LY/MIN)
C                        Z(3)    AIR TEMPERATURE (DEG C)
C                        Z(4)    DAYLENGTH
C                        Z(5)    DEW POINT TEMPERATURE
C                        Z(6)    DAYTIME TEMPERATURE
C                        Z(7)    NIGHTTIME TEMPERATURE
C                        Z(14)   WIND SPEED
C
C                 READ THE DRIVING VARIABLES FOR THE DAY.
C
      READ ( 5 , 1000 )
     >   Z(1) , Z(6) , Z(7) , Z(3) , Z(5) , Z(2) , Z(14) , Z(4)
 1000 FORMAT ( 7X , F7.2 , 5F7.3 , F10.6 , F6.3 )
C
C                 CONVERT DAILY PRECIPITATION TO TONS/HA
C
      Z(1) = 254.0 * Z(1)
C
C                 ELIMINATE NEGATIVE VAPOR PRESSURE DEFICITS CAUSED BY
C                 BAD DATA.  SET DEW POINT TEMPERATURE TO AVERAGE NIGHTTIME
C                 TEMPERATURE Z(7).
C
      IF ( Z(5) .GT. Z(3) )
     >   Z(5) = Z(7)
      IF (  Z(7) .GT. Z(3)  .AND.  Z(5) .GT. Z(3)  )
     >   Z(5) = Z(3)
C
C                 DUMMY WIND SPEED
C
      IF ( KT1 .LT. 388 )
     >   Z(14) = 0.5
      RETURN
      END
C
C**************************************************************************
C
      SUBROUTINE YUP
C
C             THIS ROUTINE PRODUCES ALL OUTPUT VARIABLES NOT SPECIFICALLY
C             CALCULATED AS INTERMEDIATE, STATE, OR DRIVING VARIABLES.
C
C---Y(1)----------- TOTAL WEEKLY EVAPORATION
C
      Y(1) = 7.0 * S3 (  10  ,  G(7) + G(8) + G(22)   )
C
C---Y(2)----------- TOTAL WEEKLY TRANSPIRATION
C
      Y(2) = 7.0 * S3 ( 11 , G(20) )
C
C---Y(4)----------- TOTAL WEEKLY PRECIPITATION
C
      Y(4) = 7.0 * S3 ( 13 , Z(1) )
C
C---Y(5)----------- TOTAL WEEKLY SNOW FALL
```

```
C
      Y(5) = 7.0 * S3 ( 14 , G(115) )
C
C---Y(6)----------- TOTAL LITTER RESPIRATION
C
      Y(6) = G(103) + G(111) + G(113) + G(125)
C
C---Y(7)----------- TOTAL SOIL ORGAINIC MATTER RESPIRATION
C
      Y(7) = G(131) + G(133) + G(139) + G(140)
C
C---Y(8)----------- TOTAL CONDENSATION AND CONVECTION HEAT INPUT TO SNO
C
      Y(8) = G(2) + G(170)
C
C---Y(9)----------- NET NEW FOLIAGE ASSIMILATION
C
      Y(9) = G(24) - G(25)
C
C---Y(10)---------- NET OLD FOLIAGE ASSIMILATION
C
      Y(10) = G(29) - G(30)
C
C---Y(11)---------- TOTAL PLANT RESPIRATION
C
      Y(11) = G(25) + G(31)
C
C---Y(12)---------- TOTAL FOREST FLOOR RESPIRATION
C
      Y(12) = G(103) + G(111) + G(113) + G(125) +
     >        G(131) + G(133) + G(139) + G(140)
C
C---Y(13)---------- TEMPORARY FOR SENSITIVITY ANALYSIS. -- NO. OF DAYS
C                   SNOW WAS ON THE GROUND.
C
      IF ( X(2) .GT. 0.0 ) Y(13) = Y(13) + 1.0
C
C
C---Y(14)---------- AVERAGE WEEKLY LITTER H2O AS PERCENT HOLDING CAP.
C
      Y(14) = S3 (  16  ,  X(7) / G(55) * 100.0  )
C
C---Y(15)---------- SOIL WATER PERCENT OF RETENTION CAPACITY
C
      Y(15) = 100.0 * ( X(3) - B(83) ) / B(13)
C
C---Y(16)---------- NET FOLIAR ASSIMILATION
C
      Y(16) = G(24) - G(25) + G(29) - G(30)
C
C---Y(17)---------- AVERAGE WEEKLY PERCENT SOLAR RADTATION INTERCEPTED
C
      Y(17) = S3 (  15  ,  100.0 * ( 1.0 - G(91) / G(59) )  )
C
C---Y(18)---------- AVERAGE WEEKLY CANOPY FOLIAR H20
C
      Y(18) = S3 ( 17 , X(1) )
C
C---Y(19)---------- AVERAGE WEEKLY CNOPY NONFOLIAR H20
C
```

```
      Y(19) = S3 ( 18 , X(8) )
C
      RETURN
      END
C
C***********************************************************************
C
      FUNCTION S1 ( T1 )
C
C                 COMPUTES E(S) AND E(A) FROM TETENS ECUATON
C
      S1 = B(153) * EXP (  B(72) * T1 / ( T1 + B(18) )   )
C
      RETURN
      END
C
C***********************************************************************
C
      FUNCTION S2 ( T1 , T2 , T3 , T4 )
C
C                 GENERALIZED BETA FUNCTION
C
      S2 = ( T1 - T2 ) * ( T3 - T1 )**( T4 - 1.0 )
      IF ( T1 .LT. T2 .OR. T1 .GT. T3 )
     >   S2 = 0.0
      RETURN
C
      END
C
C***********************************************************************
C
      FUNCTION S3 ( I , T1 )
C
C                 MAINTAINS WEEKLY SUMMATION OF T1 FOR A PARTICULAR I
C                 AND RETURNS WEEKLY AVERAGE IN FUNCTION NAME EVERY
C                 SEVENTH CALL.
C
      DIMENSION DAILY ( 100 )
C
C                 INITIALIZE SUMMER FOR THE ITH FUNCTION
C
      K1 = TSTART + 1.0
      IF ( K .NE. K1 )
     >   GO TO 10
C     ELSE
         DAILY(I) = 0.0
         S3 = T1
         RETURN
C
C                 ADD TODAYS VALUE TO SUMMER, RETURN IF NOT TIME TO
C                 COMPUTE AVERAGE.
C
   10 DAILY(I) = DAILY(I) + T1
      IF ( KT .EQ. 0 )
     >   GO TO 50
C     ELSE
         S3 = 0.0
         RETURN
C
C                 RETURN WEEKLY AVERAGE AND ZERO SUMMER.
```

```
C
   50 S3 = DAILY(I) / 7.0
      DAILY(I) = 0.0
      RETURN
C
      END
C
C**********************************************************************
C
      FUNCTION S4 ( T1 )
C
C                 COMPUTES LONGWAVE RADIATION FROM A BLACK BODY.
C
      S4 = 1.17E-7 * ( T1 + 273.16 )**4
C
      RETURN
      END
C
C**********************************************************************
C
      FUNCTION S5 ( DUM )
C
C                 COMPUTES ALBEDO OF SNOWPACK OR LITTER
C
      DIMENSION   FACUM ( 15 ) , FMELT ( 15 )
C
      DATA FACUM/
     >   0.80 , 0.77 , 0.75 , 0.72 , 0.70 , 0.69 , 0.68 , 0.67 , 0.66 ,
     >   0.65 , 0.64 , 0.63 , 0.62 , 0.61 , 0.60 /
C
      DATA FMELT/
     >   0.72 , 0.65 , 0.60 , 0.58 , 0.56 , 0.54 , 0.52 , 0.50 , 0.48 ,
     >   0.46 , 0.44 , 0.43 , 0.42 , 0.41 , 0.40 /
C
      IF ( DUM .EQ. 1.0 )
     >   GO TO 40
C     ELSE
         IF ( TIME .NE. TSTART )
     >      GO TO 40
C        ELSE
            LASTUSD = 0.0
            INT = 0.0
   10    IF ( G(115) .LE. 0.0 .OR. Z(6) .LE. B(6) )
     >      GO TO 20
C        ELSE
            INT = 0
            S5 = 0.81
            LASTUSD = 1
            IF ( G(160) .LT. 0.0 )
     >         S5 = 0.91
            IF ( G(160) .LT. 0.0 )
     >         LASTUSD = 0
            RETURN
C
C              LASTUSD IS A SWITCH FOR WHETHER FMELT OR FACUM IS TO BE
C              USED.  LASTUSD = 1 IMPLIES FMELT TO BY USED (IT IS A
C              MELTING PHASE).
C
   20    INT = INT + 1
         S5 = FACUM(INT)
```

```
         IF ( LASTUSD .EQ. 1 .AND. INT .LE. 15 )
     >      S5 = FMELT(INT)
         IF ( LASTUSD .EQ. 0 .AND. INT .GE. 15 )
     >      GO TO 30
C        ELSE
            IF ( LASTUSD .EQ. 1 .AND. INT .GE. 15 )
     >         S5 = FMELT(5)
            RETURN
C
   30    INT = 4
         LASTUSD = 1
         RETURN
C
C                 SET LITTER ALBEDO EQUAL TO .1
C
   40 S5=.1
      RETURN
C
      END
C
C************************************************************************
C
      FUNCTION S6 ( T1 , T2 , T3 )
C
C                 THIS FUNCTION IS USED FOR ACUTE PERTURBATIONS
C
      S6 = 0.0
      IF ( TIME .EQ. T1 .OR. TIME .EQ. T2 )
     >   S6 = T3
C
      RETURN
      END
```

Addendum

As this bulletin was going to press, two instances were noted in which there was substantive disagreement between documentation and code. In both cases the documentation was correct and the code was in error. Neither significantly affected behavior of the model.

The first case occurred in G_{32}, where in the code the fifth FORTRAN statement [IF (tl .LE. 0.0) G(32)=G(45)] should be deleted and the preceding statement should read G(32) = G(45).

The second case occurred in G_{79}, where the second statement should read IF (KTW .EQ. M(1)) G(79)=X(16) - G(95) + G(33).

APPENDIX II. Listing of Input File for SIMCOMP

The input file listing of Appendix II is reproduced directly from computer output.

```
TSTART     =     131.          $
TEND       =     859.          $
DT         =       1.          $
DTPR       =      91.          $
DTPL       =       7.          $
K          =       1           $
KWK        =       1           $
KMD        =       1           $
KT         =       1           $
KT1        =       1           $
G          =     200*0.0       $
X          =      99*0.0       $
Y          =      30*0.0       $
B          =     225*0.0       $
M          =       5*0         $
Z          =      25*0.0       $
X(3)       =     2960.0        $
X(4)       =     9970.0        $
X(5)       =    11896.0        $
X(7)       =      129.5        $
X(9)       =       28.9        $
X(10)      =        0.3183     $
X(11)      =        4.554      $
X(12)      =       15.45       $
X(13)      =      261.12       $
X(14)      =       73.85       $
X(15)      =        4.813      $
X(16)      =        0.555E-16  $
X(17)      =        0.0374     $
X(18)      =       15.19       $
X(19)      =       10.97       $
X(20)      =       13.429      $
X(21)      =       33.28       $
X(22)      =       78.13       $
X(25)      =        7.5        $
X(26)      =        4.1        $
X(38)      =        0.01249    $
X(62)      =        6.197      $
M(1)       =       18          $
M(2)       =       18          $
M(3)       =       40          $
M(4)       =       40          $
M(5)       =       35          $
B(1)       =        1.5        $
B(2)       =        1.0        $
B(3)       =        1.34       $
B(4)       =        0.7        $
B(5)       =     1819.0        $
B(6)       =        3.0        $
B(7)       =        1.54       $
B(9)       =        2.16       $
B(10)      =        1.08       $
B(11)      =        0.36       $
B(12)      =        0.1        $
B(13)      =     3204.0        $
B(14)      =     9970.0        $
B(15)      =        0.172      $
B(16)      =    11896.0        $
B(17)      =        3.3        $
B(18)      =      237.3        $
```

```
B(19)    =    -2.5        $
B(20)    =     0.7        $
B(21)    =     0.051      $
B(22)    =     0.28       $
B(23)    =     4.6        $
B(24)    =     0.036      $
B(25)    =     3.5        $
B(26)    =     0.0219     $
B(27)    =     1.11       $
B(28)    =     0.215      $
B(29)    =     0.078      $
B(30)    =     0.00636    $
B(31)    =     0.000323   $
B(32)    =    13.05       $
B(33)    =     0.000568   $
B(34)    =     0.1        $
B(35)    =     0.52       $
B(36)    =     0.0386     $
B(37)    =   120.0        $
B(38)    =     0.3        $
B(39)    =     0.38       $
B(40)    =     0.1        $
B(41)    =     0.000624   $
B(42)    =     0.1        $
B(43)    =     0.248E-22  $
B(44)    =     0.1        $
B(45)    =     0.378      $
B(46)    =     6.0        $
B(47)    =     0.095      $
B(48)    =     6.0        $
B(49)    =     0.0295     $
B(50)    =     0.07       $
B(51)    =     0.000447   $
B(52)    =     0.00039    $
B(53)    =     0.00257    $
B(54)    =     0.0361     $
B(56)    =     0.0014     $
B(57)    =     0.0001     $
B(58)    =     0.0001     $
B(59)    =     0.0001     $
B(60)    =     1.1        $
B(61)    =     0.00177    $
B(62)    =     0.00247    $
B(63)    =     0.00384    $
B(64)    =     0.25       $
B(65)    =     0.00118    $
B(66)    =     0.25       $
B(67)    =  2662.0        $
B(68)    =     0.00913    $
B(69)    =     0.5        $
B(71)    =     0.564      $
B(72)    =    17.27       $
B(73)    =   150.0        $
B(74)    =     0.25       $
B(75)    =     0.05       $
B(76)    =    45.0        $
B(77)    =     1.35       $
B(78)    =     4.7        $
B(79)    =    -2.0        $
B(82)    =  2104.0        $
```

```
B(84)      =     32.7        $
B(85)      =      0.09825    $
B(86)      =    300.0        $
B(87)      =     19.0        $
B(88)      =      1.9435     $
B(89)      =      0.265      $
B(91)      =     13.0        $
B(92)      =      0.5        $
B(93)      =   3000.0        $
B(94)      =      0.1494     $
B(95)      =      0.1        $
B(141)     =      0.069      $
B(145)     =      0.073      $
B(146)     =      0.00122    $
B(147)     =      0.5        $
B(148)     =      0.6        $
B(149)     =      0.4        $
B(150)     =      0.228      $
B(152)     =      0.002885   $
B(153)     =      6.11       $
B(154)     =      1.2        $
B(155)     =   1000.0        $
B(156)     =      0.3        $
B(157)     =      0.25E7     $
B(158)     =      0.66       $
B(159)     =      0.864E6    $
B(160)     =      0.1        $
B(163)     =      0.001      $
B(164)     =      0.48       $
B(165)     =     10.0        $
B(166)     =      0.0        $
B(167)     =      0.0        $
B(168)     =      0.0        $
B(170)     =     10.0        $
B(171)     =      1.0        $
B(172)     =      0.01       $
B(173)     =      0.015      $
B(174)     =      0.19       $
B(176)     =     45.0        $
B(177)     =      2.5        $
B(178)     =     45.0        $
B(179)     =      1.35       $
B(180)     =     45.0        $
B(181)     =      1.35       $
B(182)     =      0.003      $
B(183)     =      0.4        $
B(184)     =      0.0        $
B(185)     =      0.0        $
B(186)     =      0.0        $
PRINT.
PLOT. ( X(3) )
PLOT. ( X(12) )
```

APPENDIX III. Listing of Driving Variable Data

The driving variable listing in Appendix III is reproduced directly from computer output.

Date	Total precipitation (in)	Daytime temperature (°C)	Nighttime temperature (°C)	Air temperature (°C)	Dew point temperature (°C)	Average radiation (ly/min)	Wind speed (m/sec)	Day length (fraction of day)
72131	0.00	14.750	3.833	9.292	3.167	.817	0.000000	.500
72132	0.00	16.385	6.909	12.042	5.542	.754	0.000000	.542
72133	0.00	22.154	8.273	15.792	7.708	.715	0.000000	.542
72134	0.00	22.214	9.900	17.083	8.583	.657	0.000000	.583
72135	0.00	19.857	9.800	15.667	8.667	.614	0.000000	.583
72136	.20	13.000	7.667	10.333	7.542	.333	0.000000	.500
72137	.70	11.455	8.077	9.625	9.500	.182	0.000000	.458
72138	.46	7.250	5.500	6.375	5.583	.375	0.000000	.500
72139	.38	8.083	3.917	6.000	4.417	.692	0.000000	.500
72140	.02	16.385	4.909	11.125	5.792	.700	0.000000	.542
72141	0.82	15.000	11.067	12.542	9.000	.611	0.000000	.375
72142	.51	8.333	7.933	8.083	8.083	.189	0.000000	.375
72143	.12	11.000	8.000	9.375	8.875	.355	0.000000	.458
72144	0.00	9.750	5.417	7.583	4.542	.558	0.000000	.500
72145	0.00	13.250	3.500	8.375	3.667	.842	0.000000	.500
72146	0.00	17.250	6.000	11.625	6.167	.775	0.000000	.500
72147	0.00	23.000	9.167	16.083	7.875	.808	0.000000	.500
72148	0.00	25.769	11.091	19.042	9.750	.715	0.000000	.542
72149	0.00	27.462	14.455	21.500	11.833	.754	0.000000	.542
72150	0.00	21.833	13.167	17.500	8.875	.792	0.000000	.500
72151	0.00	21.231	11.273	16.667	9.167	.777	0.000000	.542
72152	0.00	17.154	10.091	13.917	8.042	.823	0.000000	.542
72153	0.00	18.462	8.909	14.083	7.917	.846	0.000000	.542
72154	.04	20.357	11.100	16.500	9.792	.743	0.000000	.583
72155	.02	16.231	11.364	14.000	9.500	.823	0.000000	.542
72156	0.00	19.692	9.727	15.125	9.667	.792	0.000000	.542
72157	0.00	22.077	12.091	17.500	11.583	.800	0.000000	.542
72158	0.00	21.154	13.091	17.458	13.333	.600	0.000000	.542
72159	.03	19.692	14.727	17.417	14.333	.485	0.000000	.542
72160	.12	18.786	12.200	16.042	13.667	.636	0.000000	.583
72161	.35	12.286	8.300	10.625	9.375	.379	0.000000	.583
72162	.25	8.500	5.100	7.083	6.083	.550	0.000000	.583
72163	.04	12.417	6.000	9.208	6.458	.817	0.000000	.500
72164	0.00	15.923	6.545	11.625	6.958	.838	0.000000	.542
72165	0.00	19.385	9.455	14.833	9.250	.831	0.000000	.542
72166	0.00	19.214	11.500	16.000	11.042	.764	0.000000	.583
72167	0.00	13.357	11.500	12.583	10.125	.343	0.000000	.583
72168	0.00	13.786	8.100	11.417	8.208	.414	0.000000	.583
72169	0.00	17.769	7.182	12.917	6.583	.869	0.000000	.542
72170	0.00	18.462	6.909	13.167	8.708	.862	0.000000	.542
72171	0.00	20.692	9.727	15.667	9.000	.846	0.000000	.542
72172	0.00	18.733	9.667	15.333	8.708	.767	0.000000	.625
72173	0.00	17.692	9.545	13.958	8.208	.908	0.000000	.542
72174	0.00	17.214	9.000	13.792	6.667	.814	0.000000	.583
72175	0.00	12.000	9.273	10.750	6.875	.477	0.000000	.542
72176	.07	10.615	8.636	9.708	7.458	.277	0.000000	.542
72177	0.00	13.286	7.900	11.042	8.292	.543	0.000000	.583
72178	0.00	15.308	8.636	12.250	9.000	.615	0.000000	.542
72179	0.00	21.769	9.818	16.292	9.625	.854	0.000000	.542
72180	0.00	23.769	10.727	17.792	9.375	.838	0.000000	.542
72181	0.00	23.929	11.400	18.708	10.667	.786	0.000000	.583
72182	0.00	22.267	12.556	18.625	10.958	.707	0.000000	.625

72183	0.00	23.214	11.800	18.458	10.125	.771	0.000000	.583
72184	0.00	24.786	13.800	20.208	4.125	.764	0.000000	.583
72185	0.00	27.286	14.600	22.000	6.833	.707	0.000000	.583
72186	0.00	27.429	15.500	22.458	10.208	.693	0.000000	.583
72187	0.00	26.143	15.700	21.792	12.458	.693	0.000000	.583
72188	0.00	20.143	11.700	16.625	10.375	.721	0.000000	.583
72189	0.00	20.286	10.300	16.125	7.750	.757	0.000000	.583
72190	0.00	13.071	9.700	11.667	7.667	.657	0.000000	.583
72191	0.00	16.867	8.111	13.583	7.208	.740	0.000000	.625
72192	0.00	19.267	10.000	15.792	7.250	.667	0.000000	.625
72193	0.00	22.714	15.400	19.667	11.875	.629	0.000000	.583
72194	0.00	25.000	15.100	20.875	11.000	.707	0.000000	.583
72195	0.00	25.286	18.400	22.417	13.500	.650	0.000000	.583
72196	0.00	25.000	15.100	20.875	12.750	.686	0.000000	.583
72197	0.00	27.000	16.100	22.458	13.417	.700	0.000000	.583
72198	0.00	28.286	16.500	23.375	12.542	.686	0.000000	.583
72199	0.00	28.500	16.900	23.667	12.500	.693	0.000000	.583
72200	0.00	22.643	13.500	18.833	8.583	.743	0.000000	.583
72201	0.00	22.000	11.900	17.792	5.292	.743	0.000000	.583
72202	0.00	19.214	9.500	15.167	6.167	.529	0.000000	.583
72203	0.00	21.071	10.800	16.792	7.083	.379	0.000000	.583
72204	0.00	23.857	12.300	19.042	7.708	.686	0.000000	.583
72205	0.00	22.714	14.700	19.375	8.625	.671	0.000000	.583
72206	0.00	22.571	13.300	18.708	9.708	.693	0.000000	.583
72207	0.00	21.500	11.500	17.333	9.542	.686	0.000000	.583
72208	0.00	20.500	11.200	16.625	9.167	.750	0.000000	.583
72209	0.00	23.385	11.455	17.917	8.667	.769	0.000000	.542
72210	0.00	25.385	13.909	20.125	11.042	.762	0.000000	.542
72211	0.00	25.615	15.182	20.833	11.417	.731	0.000000	.542
72212	0.00	27.385	15.364	21.875	10.833	.746	0.000000	.542
72213	0.00	22.692	14.182	18.792	10.542	.738	0.000000	.542
72214	0.00	21.462	11.909	17.083	9.542	.792	0.000000	.542
72215	0.00	20.615	10.091	15.792	8.250	.800	0.000000	.542
72216	0.00	25.462	12.727	19.625	9.250	.738	0.000000	.542
72217	0.00	26.000	14.273	20.625	10.333	.754	0.000000	.542
72218	0.00	28.154	16.182	22.667	12.042	.723	0.000000	.542
72219	0.00	29.769	17.818	24.292	13.000	.708	0.000000	.542
72220	0.00	30.538	18.364	24.958	12.750	.692	0.000000	.542
72221	0.00	28.000	18.083	23.042	12.042	.617	0.000000	.500
72222	0.00	26.833	16.750	21.792	11.333	.767	0.000000	.500
72223	0.00	25.154	14.182	20.125	10.000	.738	0.000000	.542
72224	0.00	21.308	11.818	16.958	8.167	.723	0.000000	.542
72225	0.00	18.071	9.400	14.458	7.000	.714	0.000000	.583
72226	0.00	18.308	9.727	14.375	5.583	.738	0.000000	.542
72227	0.00	16.769	10.364	13.833	6.833	.569	0.000000	.542
72228	.15	13.538	10.273	12.042	8.167	.377	0.000000	.542
72229	.84	13.909	9.231	11.375	9.292	.500	0.000000	.458
72230	.06	15.083	9.167	12.125	9.500	.725	0.000000	.500
72231	0.00	17.462	8.636	13.417	9.125	.538	0.000000	.542
72232	0.00	20.917	12.417	16.667	10.958	.783	0.000000	.500
72233	0.00	18.636	12.846	15.500	10.417	.609	0.000000	.458
72234	0.00	20.077	12.091	16.417	11.167	.600	0.000000	.542
72235	0.00	19.417	12.167	15.792	9.708	.692	0.000000	.500
72236	0.00	21.818	10.462	15.667	9.000	.800	0.000000	.458
72237	0.00	21.583	12.583	17.083	11.167	.658	0.000000	.500
72238	0.00	24.667	13.750	19.208	11.750	.667	0.000000	.500
72239	0.00	26.500	15.250	20.875	11.708	.650	0.000000	.500
72240	0.00	29.000	16.333	22.667	11.708	.600	0.000000	.500
72241	0.00	28.000	16.750	22.375	12.917	.592	0.000000	.500
72242	0.00	25.500	15.167	20.333	10.500	.608	0.000000	.500

72243	0.00	22.833	12.750	17.792	8.625	.633	0.000000	.500
72244	0.00	24.333	11.417	17.875	4.042	.625	0.000000	.500
72245	0.00	25.917	12.833	19.375	3.917	.592	0.000000	.500
72246	0.00	27.000	14.000	20.500	6.708	.583	0.000000	.500
72247	0.00	25.583	13.000	19.292	5.917	.617	0.000000	.500
72248	0.00	22.667	13.833	18.250	7.792	.558	0.000000	.500
72249	.03	16.455	13.923	15.083	9.542	.491	0.000000	.458
72250	0.00	15.917	9.750	12.833	6.542	.483	0.000000	.500
72251	0.00	19.250	8.333	13.792	6.042	.608	0.000000	.500
72252	0.00	17.167	9.750	13.458	6.917	.625	0.000000	.500
72253	.06	11.583	7.833	9.708	7.125	.458	0.000000	.500
72254	.20	13.333	6.167	9.750	5.458	.667	0.000000	.500
72255	0.00	14.583	6.500	10.542	5.000	.608	0.000000	.500
72256	0.00	15.727	8.615	11.875	4.958	.645	0.000000	.458
72257	0.00	20.833	6.917	13.875	5.125	.592	0.000000	.500
72258	0.00	22.417	9.583	16.000	6.042	.567	0.000000	.500
72259	0.00	22.583	8.917	15.750	8.292	.533	0.000000	.500
72260	0.00	21.000	9.846	14.958	6.833	.564	0.000000	.458
72261	0.00	20.818	12.385	16.250	8.792	.600	0.000000	.458
72262	.18	14.083	10.750	12.417	6.792	.275	0.000000	.500
72263	.91	7.636	7.692	7.667	4.917	.373	0.000000	.458
72264	.09	10.273	10.692	10.500	6.208	.355	0.000000	.458
72265	.77	10.909	10.077	10.458	9.125	.136	0.000000	.458
72266	.48	7.917	8.917	8.417	7.333	.375	0.000000	.500
72267	.76	5.300	5.929	5.667	3.542	.210	0.000000	.417
72268	.78	5.091	5.308	5.208	2.958	.355	0.000000	.458
72269	0.00	9.182	3.769	6.250	2.000	.555	0.000000	.458
72270	0.00	9.000	1.357	4.542	2.000	.600	0.000000	.417
72271	0.00	9.875	1.563	4.333	1.958	.825	0.000000	.333
72272	0.00	10.182	3.846	6.750	4.417	.364	0.000000	.458
72273	0.00	14.000	6.467	9.292	7.167	.689	0.000000	.375
72274	0.00	15.300	7.143	10.542	8.083	.610	0.000000	.417
72275	0.00	15.500	7.357	10.750	8.250	.590	0.000000	.417
72276	0.00	15.800	7.714	11.083	8.750	.580	0.000000	.417
72277	0.00	15.333	8.067	10.792	8.792	.544	0.000000	.375
72278	0.00	16.000	6.500	10.458	4.500	.590	0.000000	.417
72279	0.00	13.444	1.867	6.208	.958	.656	0.000000	.375
72280	0.00	15.778	4.667	8.833	-.917	.633	0.000000	.375
72281	0.00	16.444	5.200	9.417	1.208	.600	0.000000	.375
72282	0.00	14.222	7.533	10.042	1.750	.600	0.000000	.375
72283	.04	10.000	7.933	8.708	2.708	.156	0.000000	.375
72284	.58	7.000	6.533	6.708	1.542	.178	0.000000	.375
72285	.03	7.100	4.429	5.542	.583	.430	0.000000	.417
72286	0.00	11.556	7.267	8.875	2.750	.478	0.000000	.375
72287	.45	11.222	7.667	9.000	2.875	.300	0.000000	.375
72288	.04	12.200	5.429	8.250	3.000	.510	0.000000	.417
72289	0.00	10.900	4.143	6.958	3.000	.510	0.000000	.417
72290	0.00	10.600	4.357	6.958	3.000	.410	0.000000	.417
72291	0.00	10.222	4.400	6.583	3.000	.422	0.000000	.375
72292	0.00	13.000	5.667	8.417	3.000	.500	0.000000	.375
72293	0.00	10.556	3.200	5.958	3.000	.500	0.000000	.375
72294	0.00	9.300	3.143	5.708	3.000	.380	0.000000	.417
72295	.06	10.300	7.071	8.417	3.000	.260	0.000000	.417
72296	0.00	10.333	7.533	8.583	3.000	.267	0.000000	.375
72297	0.00	8.800	3.643	5.792	3.000	.440	0.000000	.417
72298	0.00	8.750	1.375	3.833	3.000	.487	0.000000	.333
72299	.07	8.900	2.214	5.000	3.000	.410	0.000000	.417
72300	.13	5.900	3.143	4.292	3.000	.310	0.000000	.417
72301	.29	5.300	2.286	3.542	3.000	.330	0.000000	.417
72302	1.12	-.250	.063	-.042	3.000	.175	0.000000	.333

72303	0.00	2.333	-1.400	0.000	3.000	.411	0.000000	.375
72304	0.00	.700	-3.143	-1.542	3.000	.350	0.000000	.417
72305	0.00	4.444	.333	1.875	3.000	.322	0.000000	.375
72306	1.14	4.750	4.000	4.250	3.000	.125	0.000000	.333
72307	.06	8.900	5.500	6.917	3.708	.290	0.000000	.417
72308	.90	8.143	6.412	6.917	5.292	.143	0.000000	.292
72309	.88	8.000	5.938	6.625	5.333	.175	0.000000	.333
72310	.23	6.000	3.429	4.500	3.000	.330	0.000000	.417
72311	.16	5.125	3.313	3.917	2.667	.112	0.000000	.333
72312	.39	6.556	4.600	5.333	4.375	.211	0.000000	.375
72313	.07	5.000	2.714	3.667	3.292	.340	0.000000	.417
72314	.50	5.375	4.063	4.500	4.500	.137	0.000000	.333
72315	.25	6.500	3.643	4.833	4.542	.230	0.000000	.417
72316	0.00	4.400	.357	2.042	1.417	.330	0.000000	.417
72317	0.00	5.111	1.267	2.708	2.167	.322	0.000000	.375
72318	0.00	5.778	3.400	4.292	3.750	.189	0.000000	.375
72319	.12	5.222	2.933	3.792	3.292	.333	0.000000	.375
72320	0.00	4.111	1.667	2.583	2.125	.278	0.000000	.375
72321	0.00	6.375	3.500	4.458	3.917	.187	0.000000	.333
72322	.51	7.375	3.500	4.792	4.000	.287	0.000000	.333
72323	.08	4.500	3.375	3.750	4.000	.212	0.000000	.333
72324	.01	5.375	3.813	4.333	4.000	.225	0.000000	.333
72325	0.00	4.857	1.765	2.667	4.000	.286	0.000000	.292
72326	.16	3.125	2.063	2.417	4.000	.262	0.000000	.333
72327	.02	2.750	1.813	2.125	4.000	.187	0.000000	.333
72328	0.00	3.625	2.875	3.125	4.000	.287	0.000000	.333
72329	.04	4.000	3.313	3.542	4.000	.162	0.000000	.333
72330	.61	4.333	5.778	5.417	4.000	.100	0.000000	.250
72331	.32	7.375	4.625	5.542	4.000	.162	0.000000	.333
72332	0.00	.500	.438	.458	4.000	.250	0.000000	.333
72333	.23	3.286	2.824	2.958	4.000	.200	0.000000	.292
72334	0.00	5.143	4.294	4.542	4.000	.200	0.000000	.292
72335	0.00	1.000	.412	.583	4.000	.329	0.000000	.292
72336	0.00	.667	-.778	-.417	4.000	.300	0.000000	.250
72337	.74	5.500	2.278	3.083	4.000	.100	0.000000	.250
72338	.12	.571	-1.529	-.917	4.000	.229	0.000000	.292
72339	0.00	-6.571	-7.118	-6.958	4.000	.286	0.000000	.292
72340	.64	-6.500	-7.111	-6.958	4.000	.133	0.000000	.250
72341	.12	-8.000	-7.867	-7.917	4.000	.133	0.000000	.375
72342	.05	-9.889	-9.867	-9.875	4.000	.133	0.000000	.375
72343	0.00	-10.000	-10.000	-10.000	4.000	.133	0.000000	.375
72344	0.00	-8.667	-9.933	-9.458	4.000	.133	0.000000	.375
72345	0.00	-9.222	-10.000	-9.708	4.000	.133	0.000000	.375
72346	.10	-7.889	-7.733	-7.792	4.000	.133	0.000000	.375
72347	.79	-2.889	-4.000	-3.583	4.000	.133	0.000000	.375
72348	0.00	-3.444	-4.333	-4.000	4.000	.133	0.000000	.375
72349	.01	-7.556	-6.400	-6.833	4.000	.133	0.000000	.375
72350	.02	-3.333	-4.200	-3.875	4.000	.133	0.000000	.375
72351	1.94	-1.222	-1.467	-1.375	4.000	.133	0.000000	.375
72352	1.97	-.222	-.867	-.625	4.000	.133	0.000000	.375
72353	.57	-.222	-.267	-.250	4.000	.133	0.000000	.375
72354	1.61	1.000	.800	.875	4.000	.133	0.000000	.375
72355	1.49	1.778	2.467	2.208	4.000	.133	0.000000	.375
72356	1.00	6.333	4.133	4.958	4.000	.133	0.000000	.375
72357	1.46	5.111	4.467	4.708	4.000	.133	0.000000	.375
72358	1.40	3.444	3.667	3.583	4.000	.133	0.000000	.375
72359	.96	.778	1.467	1.208	4.000	.133	0.000000	.375
72360	0.00	2.667	-.167	.542	4.000	.183	0.000000	.250
72361	.36	2.675	1.500	1.958	4.000	.150	0.000000	.333
72362	1.23	3.500	2.714	3.042	4.000	.100	0.000000	.417

72363	.29	2.250	.686	1.208	4.000	.225	0.000000	.333
72364	0.00	1.000	-.250	.167	4.000	.212	0.000000	.333
72365	.39	1.333	.600	.875	4.000	.167	0.000000	.375
72366	0.00	2.500	.688	1.292	4.000	.225	0.000000	.333
73 1	.29	.444	.267	.333	4.000	.222	0.000000	.375
73 2	.47	0.000	-.125	-.083	4.000	.175	0.000000	.333
73 3	.56	-.333	-2.400	-1.625	4.000	.175	0.000000	.375
73 4	0.00	-5.000	-6.867	-6.542	4.000	.175	0.000000	.375
73 5	.31	-3.667	-4.200	-4.000	4.000	.175	0.000000	.375
73 6	.08	-4.333	-5.467	-5.042	4.000	.175	0.000000	.375
73 7	0.00	-8.222	-9.267	-8.875	4.000	.175	0.000000	.375
73 8	.04	-7.111	-8.867	-8.208	4.000	.175	0.000000	.375
73 9	.04	-3.889	-5.533	-4.917	4.000	.175	0.000000	.375
73 10	.73	-1.889	-2.733	-2.417	4.000	.175	0.000000	.375
73 11	.38	-.333	-1.000	-.750	4.000	.175	0.000000	.375
73 12	2.09	1.000	.800	.875	4.000	.175	0.000000	.375
73 13	1.13	3.000	1.533	2.083	4.000	.156	0.000000	.375
73 14	.00	3.333	1.533	2.208	4.000	.256	0.000000	.375
73 15	.50	3.375	1.625	2.208	4.000	.137	0.000000	.333
73 16	.98	3.750	1.875	2.500	4.000	.237	0.000000	.333
73 17	.30	3.333	1.467	2.167	4.000	.256	0.000000	.375
73 18	.60	3.250	.125	1.167	4.000	.125	0.000000	.333
73 19	.27	-.429	-1.176	-.958	4.000	.100	0.000000	.292
73 20	.45	1.400	-.368	0.000	4.000	.100	0.000000	.208
73 21	0.00	1.714	-.765	-.042	4.000	.114	0.000000	.292
73 22	0.00	-.250	-2.125	-1.500	4.000	.187	0.000000	.333
73 23	0.00	-1.000	-2.600	-2.000	4.000	.211	0.000000	.375
73 24	.60	-.200	-1.105	-.917	4.000	.100	0.000000	.208
73 25	.10	-.250	-2.063	-1.458	4.000	.237	0.000000	.333
73 26	0.00	-2.500	-4.667	-4.125	4.000	.417	0.000000	.250
73 27	0.00	-1.444	-2.867	-2.333	4.000	.289	0.000000	.375
73 28	0.00	.250	-2.375	-1.500	4.000	.362	0.000000	.333
73 29	.42	-1.429	-2.059	-1.875	4.000	.114	0.000000	.292
73 30	.67	.143	-1.059	-.708	4.000	.114	0.000000	.292
73 31	.12	.625	-1.875	-1.042	4.000	.300	0.000000	.333
73 32	0.00	.333	-2.533	-1.458	4.000	.278	0.000000	.375
73 33	0.00	2.111	-.867	.250	4.000	.311	0.000000	.375
73 34	.06	2.667	-.133	.917	4.000	.244	0.000000	.375
73 35	.59	3.875	2.125	2.708	4.000	.312	0.000000	.333
73 36	.24	5.875	2.875	3.875	4.000	.287	0.000000	.333
73 37	0.00	2.222	-.667	.417	4.000	.278	0.000000	.375
73 38	0.00	3.625	-1.188	.417	4.000	.250	0.000000	.333
73 39	0.00	5.222	.267	2.125	4.000	.333	0.000000	.375
73 40	.12	6.125	1.250	2.875	4.000	.337	0.000000	.333
73 41	.71	4.889	1.067	2.500	4.000	.344	0.000000	.375
73 42	.02	3.875	-.688	.833	4.000	.462	0.000000	.333
73 43	.23	3.333	-.400	1.000	4.000	.389	0.000000	.375
73 44	0.00	5.714	-.588	1.250	4.000	.543	0.000000	.292
73 45	.08	4.444	1.067	2.333	4.000	.222	0.000000	.375
73 46	.05	5.778	2.467	3.708	4.000	.367	0.000000	.375
73 47	.08	7.000	3.133	4.583	4.000	.356	0.000000	.375
73 48	.35	2.444	3.000	2.792	4.000	.289	0.000000	.375
73 49	0.00	3.889	-.533	1.125	4.000	.444	0.000000	.375
73 50	0.00	5.111	-2.000	.667	4.000	.489	0.000000	.375
73 51	0.00	7.125	-1.625	1.292	4.000	.550	0.000000	.333
73 52	0.00	10.429	-1.176	2.208	4.000	.629	0.000000	.292
73 53	0.00	5.889	-.600	1.833	4.000	.411	0.000000	.375
73 54	0.00	6.111	-.400	2.042	4.000	.467	0.000000	.375
73 55	.15	9.571	3.882	5.542	4.000	.300	0.000000	.292
73 56	.20	9.000	5.333	6.708	4.000	.356	0.000000	.375

73 57	.37	6.222	4.867	5.375	4.000	.144	0.000000	.375
73 58	.08	7.800	5.357	6.375	4.000	.390	0.000000	.417
73 59	.80	6.333	4.800	5.375	4.000	.156	0.000000	.375
73 60	.77	2.700	1.857	2.208	4.000	.230	0.000000	.417
73 61	.02	5.091	1.154	2.958	4.000	.473	0.000000	.458
73 62	.24	3.364	1.462	2.333	4.000	.218	0.000000	.458
73 63	.19	3.909	1.846	2.792	4.000	.427	0.000000	.458
73 64	.07	5.091	3.077	4.000	4.000	.427	0.000000	.458
73 65	.19	6.000	3.308	4.542	4.000	.327	0.000000	.458
73 66	0.00	7.455	3.231	5.167	4.000	.464	0.000000	.456
73 67	0.00	8.091	3.923	5.833	4.000	.527	0.000000	.458
73 68	.13	5.818	4.769	5.250	4.000	.264	0.000000	.458
73 69	1.29	4.100	1.786	2.750	4.000	.420	0.000000	.417
73 70	.03	3.545	-.538	1.333	4.000	.573	0.000000	.458
73 71	.40	1.750	-.333	.708	4.000	.233	0.000000	.500
73 72	.36	1.618	-.692	.458	4.000	.409	0.000000	.458
73 73	0.00	3.455	-.231	1.458	4.000	.491	0.000000	.458
73 74	0.00	7.727	.077	3.583	4.000	.555	0.000000	.458
73 75	.44	2.273	-.692	.667	4.000	.155	0.000000	.458
73 76	.19	1.000	-1.231	-.208	4.000	.509	0.000000	.458
73 77	.29	3.364	1.000	2.083	4.000	.445	0.000000	.456
73 78	.46	.091	.308	.208	4.000	.136	0.000000	.458
73 79	.11	2.000	.917	1.458	4.000	.133	0.000000	.500
73 80	.06	3.833	1.583	2.708	4.000	.392	0.000000	.500
73 81	.07	5.333	.417	2.875	4.000	.542	0.000000	.500
73 82	0.00	8.000	-1.000	3.125	4.000	.655	0.000000	.458
73 83	0.00	9.917	2.167	6.042	4.000	.558	0.000000	.500
73 84	0.00	7.917	1.917	4.917	4.000	.425	0.000000	.500
73 85	0.00	4.167	.500	2.333	1.833	.617	0.000000	.500
73 86	.23	2.182	.385	1.208	2.667	.382	0.000000	.458
73 87	.09	3.333	-.583	1.375	2.125	.500	0.000000	.500
73 88	.12	4.167	.500	2.333	1.958	.433	0.000000	.500
73 89	.81	4.000	1.846	2.833	4.417	.273	0.000000	.458
73 90	.19	2.800	.357	1.375	2.875	.530	0.000000	.417
73 91	.09	3.455	.154	1.667	2.667	.645	0.000000	.458
73 92	.02	7.455	.538	3.708	2.500	.736	0.000000	.456
73 93	.04	10.545	.769	5.250	2.208	.745	0.000000	.458
73 94	0.00	12.167	2.833	7.500	3.875	.675	0.000000	.500
73 95	0.00	12.091	3.000	7.167	3.500	.627	0.000000	.458
73 96	0.00	8.583	1.167	4.875	.917	.675	0.000000	.500
73 97	0.00	12.273	.538	5.917	-2.458	.782	0.000000	.458
73 98	0.00	13.750	3.417	8.583	1.375	.625	0.000000	.500
73 99	0.00	13.462	4.545	9.375	2.750	.546	0.000000	.542
73100	0.00	14.583	4.667	9.625	4.042	.633	0.000000	.500
73101	0.00	14.417	4.083	9.250	4.000	.650	0.000000	.500
73102	.41	9.455	4.692	6.875	6.750	.473	0.000000	.458
73103	.03	8.250	5.667	6.958	7.792	.375	0.000000	.500
73104	0.00	8.615	5.273	7.083	5.667	.585	0.000000	.542
73105	0.00	10.154	5.273	7.917	4.542	.600	0.000000	.542
73106	1.23	6.545	4.231	5.292	6.333	.209	0.000000	.458
73107	.71	2.077	.909	1.542	2.333	.538	0.000000	.542
73108	1.22	.455	-1.077	-.375	1.292	.345	0.000000	.456
73109	0.20	3.538	.636	2.208	3.208	.631	0.000000	.542
73110	0.02	6.769	1.000	4.125	2.875	.700	0.000000	.542
73111	0.00	11.083	2.417	6.750	4.750	.808	0.000000	.500
73112	0.00	10.077	5.455	7.958	6.333	.469	0.000000	.542
73113	.01	8.615	2.909	6.000	3.375	.531	0.000000	.542
73114	0.00	12.000	3.455	8.083	3.250	.708	0.000000	.542
73115	0.00	15.308	6.000	11.042	5.750	.692	0.000000	.542
73116	0.00	16.214	6.800	12.292	6.667	.643	0.000000	.583

73117	0.00	10.846	4.455	7.917	2.292	.631	0.000000	.542
73118	0.00	7.643	0.000	4.458	-.625	.600	0.000000	.583
73119	0.00	8.462	.455	4.792	-.750	.638	0.000000	.542
73120	0.00	12.071	1.800	7.792	.208	.607	0.000000	.583
73121	0.00	15.769	6.000	11.292	-5.000	.654	0.000000	.542
73122	0.00	13.692	8.000	11.083	-5.000	.431	0.000000	.542
73123	.13	10.429	6.100	8.625	-5.000	.457	0.000000	.583
73124	.03	6.692	6.727	6.708	-5.000	.315	0.000000	.542
73125	0.00	11.615	9.000	10.417	-5.000	.685	0.000000	.542
73126	0.00	9.833	8.583	9.208	-5.000	.675	0.000000	.500
73127	.05	9.231	7.727	8.542	-5.000	.400	0.000000	.542
73128	.53	10.667	7.250	8.958	-5.000	.558	0.000000	.500
73129	.08	9.615	5.182	7.583	-5.000	.592	0.000000	.542
73130	.07	11.733	3.889	8.792	-5.000	.592	0.000000	.625
73131	0.00	3.000	3.000	3.000	-5.000	.555	0.000000	.625
73132	0.00	3.000	3.000	3.000	-5.000	.555	0.000000	.625
73133	0.00	3.000	3.000	3.000	-5.000	.555	0.000000	.625
73134	0.00	19.385	10.364	15.250	6.333	.538	0.000000	.542
73135	0.00	23.500	13.600	19.375	13.583	.621	0.000000	.583
73136	0.00	23.769	13.000	18.883	13.167	.692	0.000000	.542
73137	0.00	23.923	12.545	18.708	11.792	.738	0.000000	.542
73138	0.00	21.000	10.727	16.292	10.375	.746	0.000000	.542
73139	0.00	16.214	8.900	13.167	7.917	.657	0.000000	.583
73140	0.00	11.429	5.300	6.875	2.667	.643	0.000000	.583
73141	0.00	16.533	4.222	11.917	5.458	.860	19.166667	.625
73142	0.00	16.214	6.7	12.250	7.958	.793	39.166667	.583
73143	.51	13.857	10.100	12.292	13.708	.350	18.750000	.583
73144	.90	7.538	7.273	7.417	10.833	.231	25.466667	.542
73145	.01	7.600	2.000	5.500	5.458	.727	22.916667	.625
73146	0.00	11.857	2.000	7.750	4.292	.843	37.916667	.583
73147	0.00	12.429	4.200	9.000	9.083	.443	28.750000	.583
73148	0.00	20.154	6.455	13.875	9.542	.892	36.666667	.542
73149	0.00	24.500	9.100	18.083	11.917	.793	35.888883	.583
73150	0.00	13.643	9.545	13.833	11.542	.677	39.166667	.542
73151	0.00	13.643	4.500	9.833	5.667	.664	.483333	.583
73152	0.00	13.214	4.800	9.708	5.500	.543	.445833	.583
73153	0.00	14.000	7.444	11.542	6.750	.647	.166667	.625
73154	0.00	15.857	7.100	12.208	9.083	.336	.387500	.583
73155	0.00	18.786	7.600	14.125	8.667	.600	.437500	.583
73156	0.00	22.214	10.500	17.333	9.667	.550	.454167	.583
73157	0.00	21.500	14.200	18.458	10.292	.443	.520833	.583
73158	0.00	19.846	12.818	16.625	9.333	.685	.479167	.542
73159	0.00	19.615	10.000	15.208	11.042	.685	.416667	.542
73160	0.00	13.857	8.100	11.458	6.375	.364	.466667	.583
73161	0.00	16.071	5.600	11.708	5.917	.593	.379167	.583
73162	0.00	18.929	10.400	15.375	7.958	.579	.366667	.583
73163	.11	2.000	9.100	.792	1.208	.236	.216667	.583
73164	0.00	12.500	8.400	10.792	8.208	.600	.375000	.583
73165	.16	9.600	6.556	8.458	7.875	.540	.350000	.625
73166	.25	1.357	7.900	9.917	9.083	.614	.279167	.583
73167	.97	7.846	5.909	6.958	8.875	.277	.304167	.542
73168	1.03	6.214	4.400	5.458	7.375	.400	.304167	.583
73169	0.00	13.462	6.727	10.375	7.583	.654	.262500	.542
73170	0.00	20.154	7.545	14.375	10.417	.677	.516667	.542
73171	0.00	24.077	11.636	18.375	13.167	.608	.383333	.542
73172	0.00	24.308	14.818	19.958	15.625	.615	.304167	.542
73173	0.00	16.917	12.250	14.583	12.542	.333	.408333	.500
73174	0.00	15.867	11.778	14.333	11.500	.393	.362500	.625
73175	.02	19.143	13.300	16.708	11.833	.443	.300000	.583
73176	.83	6.500	4.500	5.500	7.500	.123	.079167	.542

73177	.05	2.308	6.818	9.792	8.000	.585	.354167	.542
73178	0.00	22.750	15.083	18.917	16.542	.642	.395833	.500
73179	0.00	19.308	11.909	15.917	13.500	.638	.366667	.542
73180	0.00	13.538	8.545	11.250	9.542	.662	.425000	.542
73181	0.00	12.846	7.545	10.417	6.708	.577	.312500	.542
73182	0.00	16.583	9.583	13.083	7.958	.633	.383333	.500
73183	0.00	19.667	10.833	15.250	9.667	.650	.387500	.500
73184	0.00	20.250	11.833	16.042	10.625	.633	.445833	.500
73185	0.00	20.667	13.750	17.208	12.583	.683	.404167	.500
73186	0.00	17.000	14.333	15.667	11.292	.650	.566667	.500
73187	0.00	16.167	11.333	13.750	9.292	.592	.441667	.500
73188	0.00	18.583	10.333	14.458	8.333	.667	.308333	.500
73189	0.00	19.083	11.583	15.333	10.333	.675	.354167	.500
73190	0.00	21.333	12.833	17.083	11.792	.683	.395833	.500
73191	0.00	19.833	11.667	15.750	11.875	.667	.350000	.500
73192	0.00	17.583	10.583	14.083	10.292	.633	.441667	.500
73193	0.00	19.917	12.000	15.958	10.958	.600	.395833	.500
73194	0.00	23.833	21.500	22.667	8.750	.642	.404167	.500
73195	0.00	21.000	19.000	20.000	20.000	.630	.404000	.500
73196	0.00	19.000	17.000	18.000	18.000	.580	.390000	.510
73197	0.00	17.000	14.000	15.500	15.500	.550	.380000	.520
73198	0.00	16.000	10.000	13.000	13.000	.510	.370000	.530
73199	0.00	15.000	9.000	12.000	12.000	.480	.360000	.535
73200	.01	14.000	9.000	11.000	11.000	.460	.350000	.540
73201	0.00	13.154	8.273	10.917	10.917	.454	.350000	.542
73202	0.00	17.769	13.455	15.792	15.208	.477	.312500	.542
73203	0.00	18.364	11.462	14.625	12.417	.555	.354167	.458
73204	0.00	19.833	8.667	14.250	11.750	.617	.345833	.500
73205	0.00	25.000	11.000	17.417	11.750	.664	.337500	.458
73206	0.00	26.667	12.250	19.458	14.667	.558	.312500	.500
73207	0.00	30.000	14.769	21.750	16.292	.609	.295833	.458
73208	0.00	30.364	15.538	22.333	17.250	.591	.333333	.458
73209	0.00	31.636	16.154	23.250	16.750	.582	.300000	.458
73210	0.00	30.455	15.000	22.083	16.292	.582	.333333	.458
73211	0.00	29.727	13.538	20.958	12.292	.582	.337500	.458
73212	0.00	30.182	13.846	21.333	14.000	.591	.320833	.458
73213	0.00	29.636	14.462	21.417	15.625	.582	.304167	.458
73214	0.00	27.083	12.917	20.000	14.708	.542	.295833	.500
73215	0.00	27.727	13.154	19.833	14.667	.582	.337500	.458
73216	0.00	27.636	13.615	20.042	14.833	.591	.300000	.458
73217	0.00	26.545	15.385	20.500	15.375	.536	.275000	.458
73218	0.00	24.667	14.333	19.500	14.917	.558	.395833	.500
73219	0.00	26.727	12.846	19.208	10.333	.564	.337500	.458
73220	0.00	26.000	12.000	19.000	10.000	.560	.320000	.458
73221	0.00	25.000	12.000	18.000	10.000	.550	.310000	.458
73222	0.00	24.000	12.000	17.000	10.000	.540	.300000	.458
73223	0.00	23.000	12.000	17.000	10.000	.520	.280000	.458
73224	0.00	22.000	12.000	17.000	10.000	.500	.260000	.458
73225	0.00	22.182	12.077	16.708	9.542	.491	.258333	.458
73226	0.00	27.273	15.769	21.042	15.792	.545	.320833	.458
73227	0.00	24.750	12.083	18.417	11.875	.517	.337500	.500
73228	0.00	16.385	10.091	13.500	12.167	.523	.337500	.542
73229	0.00	18.182	9.385	13.417	10.042	.545	.333333	.458
73230	0.00	18.364	8.154	12.833	7.375	.591	.341667	.458
73231	0.00	22.000	9.214	14.542	9.750	.530	.337500	.417
73232	0.00	20.636	8.231	13.917	10.667	.627	.337500	.458
73233	0.00	19.182	7.462	12.833	10.542	.582	.325000	.458
73234	0.00	17.417	5.500	11.458	8.000	.525	.333333	.500
73235	0.12	15.273	6.846	10.708	10.667	.536	.254167	.458
73236	.65	12.000	9.500	10.542	15.375	.290	.095833	.417

73237	.02	16.909	9.692	13.000	15.042	.500	.183333	.458
73238	0.00	18.909	8.308	13.167	13.792	.473	.270833	.458
73239	0.00	16.182	7.077	11.250	12.292	.491	.266667	.458
73240	0.00	20.636	9.077	14.375	13.833	.500	.258333	.458
73241	0.00	21.364	10.077	15.250	15.292	.491	.316667	.458
73242	0.00	15.545	10.462	12.792	13.417	.300	.245833	.458
73243	0.00	14.182	6.769	10.167	8.250	.473	.308333	.458
73244	0.00	17.000	3.923	9.917	5.042	.536	.241667	.458
73245	0.00	21.182	6.231	13.083	7.917	.491	.187500	.458
73246	0.00	22.455	9.000	15.167	11.625	.482	.225000	.458
73247	0.00	28.600	11.286	18.500	10.875	.450	.258333	.417
73248	0.00	23.273	12.154	17.250	12.250	.436	.408333	.458
73249	0.28	17.182	14.385	15.667	14.750	.209	.312500	.458
73250	.21	10.273	4.385	7.083	10.750	.418	.075000	.458
73251	0.00	18.091	9.000	13.167	17.917	.491	.245833	.458
73252	0.00	22.818	9.846	15.792	13.875	.473	.250000	.458
73253	0.00	25.091	12.154	18.083	15.292	.409	.158333	.458
73254	0.00	23.182	12.000	17.125	16.000	.427	.245833	.458
73255	0.00	22.600	10.286	15.417	13.500	.450	.225000	.417
73256	0.00	18.909	8.923	13.500	12.167	.409	.358333	.458
73257	0.00	17.700	9.929	13.167	12.292	.390	.170833	.417
73258	0.00	19.100	7.143	12.125	9.458	.440	.220833	.417
73259	0.00	18.000	8.231	12.708	8.792	.400	.204167	.458
73260	.17	17.100	9.786	12.833	13.417	.270	.162500	.417
73261	.15	14.700	11.714	12.958	15.458	.260	.120833	.417
73262	.93	12.667	10.800	12.500	16.208	.144	.045833	.375
73263	.97	12.500	10.062	10.875	10.062	.337	.600000	.333
73264	.27	15.750	12.125	13.333	12.125	.350	.100000	.333
73265	1.11	13.286	11.471	12.000	15.125	.329	.037500	.292
73266	1.03	12.000	10.538	11.208	14.583	.182	.154167	.458
73267	1.69	10.625	10.187	10.333	13.875	.112	.262500	.333
73268	.02	12.400	8.714	10.250	11.917	.320	.083333	.417
73269	0.00	14.875	7.188	9.750	11.542	.475	.091667	.333
73270	0.00	18.625	8.568	11.917	14.333	.450	.104167	.333
73271	0.00	24.714	9.529	13.958	14.875	.429	.108333	.292
73272	0.00	19.857	11.294	13.792	15.333	.429	.245833	.292
73273	0.00	13.111	8.067	9.958	10.208	.233	.216667	.375
73274	0.00	10.857	4.529	6.375	6.208	.357	.158333	.292
73275	0.00	8.778	2.267	4.708	5.125	.389	.229167	.375
73276	0.00	10.625	3.125	5.625	6.500	.425	.225000	.333
73277	0.00	11.875	4.625	7.042	7.083	.400	.141667	.333
73278	0.00	8.600	7.214	7.792	9.125	.280	.154167	.417
73279	.28	10.600	7.789	8.375	11.292	.100	.175000	.208
73280	.07	6.000	5.625	5.750	11.542	.250	.050000	.333
73281	0.00	7.400	3.266	5.000	9.250	.270	.075000	.417
73282	0.00	10.625	1.188	4.333	9.458	.375	.208333	.333
73283	0.00	11.600	4.429	7.417	13.708	.260	.137500	.417
73284	.11	12.444	8.400	9.917	12.875	.222	.079167	.375
73285	.01	12.667	10.000	11.000	14.583	.233	.100000	.375
73286	0.00	14.700	8.714	11.208	11.542	.270	.137500	.417
73287	0.00	11.778	5.533	7.875	8.792	.300	.129167	.375
73288	0.00	14.222	3.933	7.792	8.375	.289	.145833	.375
73289	0.00	12.250	6.188	8.208	9.375	.287	.108333	.333
73290	0.00	12.125	8.125	9.458	10.833	.262	.079167	.333
73291	0.00	12.667	7.667	9.542	11.250	.244	.066667	.375
73292	.56	9.625	8.313	8.417	10.958	.188	.166667	.333
73293	.33	12.000	10.867	11.292	13.917	.133	.025000	.375
73294	1.18	9.000	8.588	8.708	11.667	.157	.066667	.292
73295	.13	9.200	6.895	7.375	11.000	.200	.066667	.208
73296	.44	7.000	6.056	6.292	10.917	.100	.091667	.250

73297	.68	7.167	4.722	5.333	9.750	.150	.050000	.250
73298	0.00	7.143	2.647	3.958	7.750	.286	.079167	.292
73299	0.00	8.857	2.529	4.375	7.875	.200	.145833	.292
73300	0.00	11.250	3.938	6.375	9.333	.200	.108333	.333
73301	.67	7.429	5.882	6.333	10.375	.114	.108333	.292
73302	.04	7.571	3.882	4.958	8.750	.214	.058333	.292
73303	.02	9.143	6.000	6.917	10.333	.100	.075000	.292
73304	2.77	10.000	6.882	7.792	11.417	.100	.529167	.292
73305	.11	2.571	.941	1.417	5.208	.114	.162500	.292
73306	0.00	1.833	-2.389	-1.333	1.792	.200	.104167	.250
73307	.53	1.286	-1.588	-.750	2.333	.100	.058333	.292
73308	1.69	-.715	-.824	-.792	2.625	.100	.187500	.292
73309	2.52	-1.000	-1.000	-1.000	2.167	.100	.016667	.292
73310	.92	-.429	-1.000	-.833	2.583	.100	.016667	.292
73311	.46	.857	-.471	-.083	3.167	.100	.062500	.292
73312	1.46	1.714	.059	.542	4.833	.100	.175000	.292
73313	.69	2.286	.824	1.250	4.833	.100	.200000	.292
73314	.52	4.286	1.765	2.500	5.000	.100	.208333	.292
73315	.94	5.143	2.765	3.458	1.000	.100	.141667	.292
73316	1.27	3.143	2.765	2.875	1.000	.100	.320833	.292
73317	1.01	1.143	2.588	2.167	1.000	.100	.041667	.292
73318	2.03	5.286	5.167	5.208	1.000	.100	0.000000	.292
73319	.87	8.000	5.750	6.125	1.000	.200	.025000	.250
73320	.52	4.000	4.083	4.083	1.000	.200	.275000	.250
73321	.11	3.000	1.958	1.958	1.000	.200	.041667	.250
73322	.12	1.000	.542	.542	1.000	.200	.104167	.250
73323	.09	1.560	-1.000	.330	-1.000	.295	.050000	.375
73324	1.72	.857	-.235	.083	.083	.197	.492000	.292
73325	1.58	.286	-.882	-.542	-.542	.286	.413000	.292
73326	.68	.444	-1.000	-.458	-.458	.242	.004000	.375
73327	1.38	-1.000	-1.000	-1.000	-1.000	.140	.058000	.250
73328	.54	1.000	-.529	-.083	-.083	.252	.096000	.292
73329	1.46	.142	-.111	-.042	-.042	.121	.242000	.250
73330	.75	.556	-.800	-.292	-.292	.200	.042000	.375
73331	1.06	1.625	.313	.750	.750	.250	.096000	.333
73332	1.18	3.330	.333	1.460	1.460	.260	.100000	.375
73333	.67	1.110	-.200	.290	.290	.290	.058000	.375
73334	.36	3.440	1.400	2.170	2.170	.330	.217000	.375
73335	.39	2.890	1.330	1.920	1.920	.330	.096000	.375
73336	.22	2.440	.470	1.210	1.210	.330	.050000	.375
73337	.66	3.440	.600	1.670	1.670	.260	.071000	.375
73338	0.00	1.000	.467	.083	.083	.340	.012000	.375
73339	.45	3.400	1.000	2.000	2.000	.330	.071000	.375
73340	.91	4.300	1.710	2.790	2.790	.200	.136000	.375
73341	1.45	5.100	2.920	3.830	3.830	.200	.010000	.375
73342	0.00	1.400	1.930	-.625	-.625	.330	.020000	.375
73343	0.00	.500	-1.790	-.833	-.833	.330	.029000	.375
73344	0.00	1.600	-.428	.417	.417	.330	.016000	.375
73345	.34	3.300	2.640	2.920	2.920	.250	.470000	.375
73346	1.37	2.000	.214	.958	.958	.150	.091000	.375
73347	.69	1.400	-.714	.166	.166	.200	.095000	.375
73348	1.40	0.000	-.714	-.416	-.416	.150	.050000	.375
73349	.10	2.700	1.280	1.875	1.875	.300	.010000	.375
73350	.89	3.100	2.860	2.960	2.960	.250	.079000	.375
73351	.99	4.440	3.467	3.833	3.833	.150	.058000	.292
73352	0.00	1.440	.200	.667	.667	.300	.221000	.375
73353	.44	1.670	.667	1.042	1.042	.220	.204000	.375
73354	1.52	4.000	3.533	3.708	3.708	.150	.067000	.375
73355	.35	5.111	2.800	3.667	3.667	.250	.046000	.375
73356	1.64	3.111	1.533	2.125	2.125	.150	.208000	.375

73357	.34	3.000	1.600	2.125	2.125	.250	.050000	.375
73358	1.50	3.222	1.333	2.042	2.042	.180	.188000	.375
73359	0.00	.667	-1.533	-.708	-1.533	.330	.079000	.375
73360	.67	.889	-.933	-.250	-.250	.230	.050000	.375
73361	2.38	3.330	4.000	3.750	3.750	.150	.036000	.375
73362	.84	3.556	1.667	2.375	2.375	.220	.175000	.375
73363	1.87	3.444	.067	1.333	1.333	.150	.333000	.375
73364	.07	.330	-.133	.166	.166	.290	.079000	.375
73365	.16	-.677	-2.600	-1.875	-2.600	.330	.229000	.375
74 1	0.00	-3.110	-6.200	-5.750	-6.200	.330	.504000	.375
74 2	0.00	-5.660	-7.730	-6.960	-7.730	.330	.667000	.375
74 3	0.00	-4.556	-7.530	-6.417	-7.530	.330	.546000	.375
74 4	0.00	-6.110	-8.800	-7.833	-8.800	.330	.667000	.375
74 5	0.00	-7.556	-9.133	-8.542	-9.133	.330	.883000	.375
74 6	0.00	-6.670	-9.133	-8.208	-9.133	.330	.100000	.375
74 7	0.00	-6.440	-8.067	-7.458	-8.067	.330	.163000	.375
74 8	0.00	-5.560	-8.667	-7.500	-8.667	.330	.192000	.375
74 9	0.00	-6.330	-8.933	-7.958	-8.933	.330	.088000	.375
74 10	0.00	-6.220	-9.000	-7.958	-9.000	.330	.038000	.375
74 11	.19	-4.440	-6.267	-5.583	-6.000	.330	.067000	.375
74 12	1.17	-.022	-1.000	-.708	-.708	.250	.050000	.375
74 13	1.25	2.778	.400	1.292	1.292	.220	.083000	.375
74 14	1.53	4.889	1.667	2.875	2.875	.220	0.000000	.330
74015	3.00	4.375	2.063	2.883	6.125	0.220	.054167	.333
74016	3.00	4.375	2.063	2.833	6.125	0.220	.054167	.333
74017	1.54	2.600	.929	1.625	8.708	.010	.062500	.417
74018	.16	6.667	3.800	4.875	11.083	0.220	.187500	.375
74019	1.32	2.667	1.600	2.000	8.583	0.220	.129167	.375
74020	.10	.778	-1.267	-.500	6.417	0.220	.108333	.375
74021	.09	-1.222	-2.200	-1.833	5.417	0.220	.016667	.375
74022	.22	.222	-.867	-.458	6.792	0.220	.020833	.375
74023	.21	1.667	.533	.958	8.083	0.220	.020833	.375
74024	.29	3.000	1.067	1.792	8.708	0.220	.054167	.375
74025	.29	2.556	1.667	2.000	8.708	0.220	.329167	.375
74026	1.40	1.889	-.267	.542	7.458	0.220	.250000	.375
74027	.49	-.667	-.800	-.750	6.417	0.220	.054167	.375
74028	1.11	1.778	0.000	.667	7.958	0.220	.045833	.375
74029	.38	2.667	1.600	2.000	9.000	0.220	.141667	.375
74030	.37	4.667	2.933	3.583	10.333	0.220	.262500	.375
74031	.31	5.111	2.600	3.542	9.958	0.220	.233333	.375
74032	2.56	2.667	1.400	1.875	8.583	0.220	.312500	.375
74033	.67	2.778	-.400	.792	7.500	0.220	.083333	.375
74034	0.00	3.667	.200	1.500	8.250	0.220	.066667	.375
74035	.51	.778	-.667	-.125	7.042	0.220	.212500	.375
74036	1.28	1.100	-1.286	-.292	6.583	0.220	.062500	.417
74037	.06	-.400	-2.571	-1.667	5.208	0.220	.037500	.417
74038	0.00	1.700	-1.786	-.333	6.250	0.220	.095833	.417
74039	0.00	3.000	-1.857	.167	6.833	0.220	.154167	.417
74040	0.00	3.600	-2.143	.250	6.792	0.220	.120833	.417
74041	0.00	4.000	-2.071	.458	6.875	0.220	.112500	.417
74042	0.00	3.300	-1.714	.375	6.458	0.220	.195833	.417
74043	0.00	1.500	-.286	.458	7.125	0.220	.137500	.417
74044	.18	3.600	.143	1.583	5.250	0.220	.012500	.417
74045	.26	3.500	.643	1.833	3.208	0.220	.058333	.417
74046	.86	1.444	-.067	.500	2.833	0.220	.062500	.375
74047	.83	.100	.500	.333	1.667	0.220	.308333	.417
74048	1.42	1.100	.143	.542	1.583	0.220	.095833	.417
74049	.31	-1.000	-.500	-.708	-.250	0.220	.079167	.417
74050	3.20	.300	0.000	.125	1.083	0.220	.216667	.417
74051	.96	.700	-.500	-.000	.917	0.220	.070833	.417

74052	.14	.400	-.500	-.125	.250	0.220	.241667	.417
74053	.82	-.300	-1.000	-.708	-1.125	0.220	.220833	.417
74054	.71	0.000	-1.000	-.583	-.833	0.220	.050000	.417
74055	0.00	.800	-.786	-.125	.208	0.220	.150000	.417
74056	0.00	1.300	.071	.583	2.167	0.220	.104167	.417
74057	.10	-.300	-.214	-.250	-.208	0.220	.325000	.417
74058	.96	.100	-.500	-.250	.042	0.220	.083333	.417
74059	.40	-.300	-.286	-.292	.125	0.220	.116667	.417
74060	.95	.909	-.538	.125	.458	0.220	.287500	.458
74061	.38	.273	-1.000	-.417	0.000	0.220	.083333	.458
74062	.26	-.455	-1.154	-.833	-1.708	0.220	.166667	.458
74063	.20	-.182	-.769	-.500	-.250	0.220	.020833	.458
74064	1.60	.636	-.231	.167	1.458	0.220	.233333	.458
74065	2.80	-.182	-1.000	-.625	-1.167	0.220	.037500	.458
74066	.05	-.636	-1.692	-1.208	-4.833	0.220	.112500	.458
74067	0.00	.364	-1.308	-.542	-2.875	0.220	.100000	.458
74068	0.00	1.818	-.538	.542	.833	0.220	.091667	.458
74069	0.00	1.364	-.231	.500	1.833	0.220	.087500	.458
74070	.12	1.636	.308	.917	3.333	0.220	.083333	.458
74071	.37	.091	-.385	-.167	.500	0.220	.341667	.458
74072	.80	.636	-.846	-.167	.458	0.220	.087500	.458
74073	.50	-.833	-.333	-.458	-.292	.017	.020833	.250
74074	2.90	9.636	3.077	6.083	7.042	.509	.004167	.458
74075	.08	5.800	3.857	4.667	6.375	.230	0.000000	.417
74076	.79	8.100	.500	3.667	3.083	.540	0.000000	.417
74077	.04	8.400	.286	3.667	1.917	.690	0.000000	.417
74078	0.00	12.273	1.462	6.417	-.083	.618	0.000000	.458
74079	0.00	8.500	-.643	3.167	-.833	.670	0.000000	.417
74080	0.00	9.400	.143	4.000	-.750	.670	0.000000	.417
74081	0.00	7.364	2.077	4.500	-.167	.564	.158333	.458
74082	0.00	9.800	1.143	4.750	.750	.680	.187500	.417
74083	0.00	11.091	2.385	6.375	2.583	.627	.175000	.458
74084	0.00	9.091	2.462	5.500	5.958	.391	.075000	.458
74085	.30	11.000	4.308	7.375	6.917	.500	.062500	.458
74086	0.00	6.545	4.692	5.542	6.417	.182	.125000	.458
74087	.43	4.273	2.077	3.083	3.875	.227	.116667	.458
74088	1.26	9.000	4.643	6.458	6.875	.420	.066667	.417
74089	1.45	3.727	2.231	2.917	3.375	.355	.375000	.458
74090	1.22	2.667	2.667	2.667	3.167	.242	.054167	.500
74091	.87	3.333	1.583	2.458	3.125	.250	.250000	.500
74092	1.50	2.333	.750	1.542	2.000	.292	.262500	.500
74093	.97	3.417	-.167	1.625	1.250	.508	.204167	.500
74094	.27	3.750	2.750	3.250	4.375	.275	.033333	.500
74095	.14	6.167	2.583	4.375	5.417	.217	.075000	.500
74096	.21	5.333	3.167	4.250	4.542	.375	.070833	.500
74097	.40	9.167	3.750	6.458	0.000	.525	0.000000	.500
74098	0.00	7.917	2.917	5.417	0.000	.342	0.000000	.500
74099	.20	2.833	1.833	2.333	2.667	.350	.337500	.500
74100	.38	5.500	3.833	4.667	4.458	.425	.154167	.500
74101	.22	6.000	.417	3.208	3.750	.242	.166667	.500
74102	1.21	5.917	-1.500	2.208	-1.167	.508	.162500	.500
74103	0.00	10.182	1.615	5.542	-.750	.282	.283333	.458
74104	0.00	13.385	3.818	9.000	.708	.562	.033333	.542
74105	0.00	7.917	1.083	4.500	0.000	.433	0.000000	.500
74106	0.00	7.917	.917	4.417	0.000	.433	0.000000	.500
74107	0.00	15.917	7.917	11.917	4.792	.658	.275000	.500
74108	0.00	8.538	3.545	6.250	3.833	.308	.241667	.542
74109	.03	6.154	3.545	4.958	2.250	.446	.266667	.542
74110	.05	8.077	6.000	7.125	5.875	.469	.141667	.542
74111	0.00	14.692	8.636	11.917	6.125.	.615	.237500	.542

74112	0.00	12.333	6.083	9.208	4.208	.492	.283333	.500
74113	.20	12.333	4.917	8.625	3.792	.492	.287500	.500
74114	.57	9.846	3.273	6.833	2.583	.608	.237500	.542
74115	.27	7.071	-.400	3.958	.667	.536	.204167	.583
74116	.14	6.857	4.700	5.958	3.042	.550	.179167	.583
74117	.02	7.727	5.538	6.542	5.042	.500	.145833	.458
74118	.12	10.714	2.900	7.458	4.208	.536	.229167	.583
74119	0.00	16.462	7.818	12.500	6.375	.585	.287500	.542
74120	0.00	13.929	6.300	10.750	6.208	.493	.258333	.583
74121	0.00	13.929	6.000	10.625	6.000	.493	.237500	.583
74122	0.00	12.286	4.200	8.917	2.625	.571	.208333	.583
74123	0.00	14.154	4.818	9.875	3.625	.638	.245833	.542
74124	0.00	18.923	8.091	13.958	5.708	.577	.233333	.542
74125	0.00	20.917	10.667	15.792	8.292	.675	.208333	.500
74126	0.00	18.769	10.545	15.000	7.833	.469	.208333	.542
74127	0.00	19.615	12.182	16.208	7.667	.546	.279167	.542
74128	0.00	17.923	7.909	13.333	4.292	.292	.383333	.542
74129	0.00	8.071	5.000	6.792	3.875	.364	.237500	.583
74130	.20	9.357	7.100	8.417	5.417	.443	.158333	.583
74131	.07	10.071	6.500	8.583	8.042	.393	.212500	.583
74132	.53	6.133	1.667	4.458	1.250	.480	.204167	.625
74133	.05	8.000	4.111	6.542	1.208	.507	.225000	.625
74134	0.00	5.385	1.455	3.583	4.625	.315	.166667	.542
74135	.74	3.231	0.000	1.750	2.083	.362	.220833	.542
74136	.65	3.000	.818	2.000	2.750	.392	.108333	.542
74137	0.00	5.000	2.000	3.750	5.125	.300	.158333	.583
74138	0.00	4.750	2.750	3.750	7.000	.308	.179167	.500
74139	0.00	7.538	4.455	6.125	7.875	.415	.108333	.542
74140	0.00	9.786	2.100	6.583	7.456	.414	.120833	.583
74141	0.00	13.077	7.273	10.417	12.292	.546	.237500	.542
74142	0.00	14.077	6.636	10.667	12.792	.531	.304167	.542
74143	0.00	14.538	8.364	11.708	13.042	.592	.245833	.542
74144	0.00	15.538	12.000	13.917	22.667	.392	.075000	.542
74145	0.00	20.462	14.273	17.625	23.292	.562	.212500	.542
74146	0.00	19.615	10.818	15.583	18.250	.585	.337500	.542
74147	0.00	16.692	4.455	11.083	9.917	.569	.254167	.542
74148	0.00	15.643	4.500	11.000	7.958	.521	.266667	.583
74149	0.00	9.000	2.500	6.292	5.542	.343	.291667	.583
74150	0.00	13.800	4.444	10.292	5.583	.493	.191667	.625
74151	0.00	20.231	7.091	14.208	12.250	.546	.254167	.542
74152	0.00	22.769	8.545	16.250	14.750	.631	.220833	.542
74153	0.00	21.077	10.000	16.000	17.542	.646	.225000	.542
74154	0.00	19.385	11.364	15.708	16.125	.500	.329167	.542
74155	0.00	11.769	9.091	10.542	19.625	.177	.275000	.542
74156	0.00	10.000	9.167	9.583	18.792	.150	.025000	.500
74157	0.00	12.538	5.818	9.458	12.583	.346	.241667	.542
74158	0.00	11.923	4.000	8.292	6.917	.508	.191667	.542
74159	0.00	15.917	8.167	12.042	14.333	.642	.258333	.500
74160	0.00	21.000	10.385	15.250	18.500	.609	.262500	.458
74161	0.00	25.385	14.545	20.417	26.792	.638	.295833	.542
74162	0.00	26.667	13.917	20.292	23.958	.658	.245833	.500
74163	0.00	26.923	13.545	20.792	25.833	.592	.258333	.542
74164	0.00	19.769	12.909	16.625	22.125	.638	.383333	.542
74165	0.00	17.769	13.818	15.958	22.958	.338	.258333	.542
74166	0.00	21.833	13.500	17.667	25.208	.575	.291667	.500
74167	0.00	24.846	15.091	20.375	27.750	.623	.320833	.542
74168	0.00	24.643	15.500	20.833	28.542	.579	.295833	.583
74169	0.00	15.308	11.182	13.417	18.292	.415	.350000	.542
74170	0.00	20.250	11.083	15.667	17.958	.700	.275000	.500
74171	0.00	24.167	12.583	18.375	21.583	.683	.262500	.500

74172	0.C0	18.750	13.083	15.917	21.208	.383	.304167	.500
74173	0.00	20.167	10.167	15.167	16.458	.708	.366667	.500
74174	0.00	21.000	10.583	15.792	14.292	.692	.300000	.500
74175	0.00	10.429	6.500	8.792	12.583	.229	.183333	.583
74176	0.0C	15.286	10.100	13.125	15.042	.414	.191667	.583
74177	0.CC	19.500	8.500	14.000	16.750	.608	.254167	.500
74178	0.00	23.182	12.923	17.625	20.667	.745	.266667	.458
74179	0.00	29.182	16.538	22.333	23.375	.700	.241667	.458
74180	0.00	26.636	14.538	20.083	22.208	.664	.287500	.458
74181	0.00	14.333	9.583	11.958	12.583	.325	.200000	.500
74182	0.CC	17.333	9.833	13.583	14.208	.625	.262500	.500
74183	0.00	23.636	12.077	17.375	16.500	.736	.316667	.458
74184	0.00	21.714	15.800	19.250	21.375	.514	.250000	.583
74185	0.00	17.154	12.455	15.000	22.458	.400	.245833	.542
74186	0.00	18.071	8.800	14.208	16.333	.457	.262500	.583

APPENDIX IV. Sample Output

The sample output of Appendix IV is reproduced directly from computer output.

PROGRAM CHARACTERISTICS

30	STATE VARIABLES
65	FUNCTIONS
6	DECLARED COMMON BLOCKS
11	USER DECLARED VARIABLES
491	AMOUNT OF USER DECLARED STORAGE
13.364	FIRST PASS COMPILATION TIME(SEC)

STATE VARIABLE LIST -

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	25	26	37	38	62	64	98	99

LIST OF FUNCTION LABELS -

106	198	199	298	304
399	405	599	607	703
799	806	808	899	920
999	1011	1017	1019	1020
1064	1117	1119	1120	1213
1214	1215	1216	1217	1264
1299	1309	1318	1462	1562
1610	1617	1720	1820	1899
1920	1999	2021	2099	2122
2199	6221	6299	6410	6412
6499	9802	9806	9901	9902
9906	9908	9912	9920	9925
9926	9937	9938	9964	9998

SIMULATION OUTPUT

TIME = 131.000000

X(1)	= 0	X(2)	= 0	X(3)	= 2960.00000	X(4)	= 9970.00000
X(5)	= 11896.0000	X(6)	= 0	X(7)	= 129.500000	X(8)	= 0
X(9)	= 28.9000000	X(10)	= .318300000	X(11)	= 4.55400000	X(12)	= 15.4500000
X(13)	= 261.120000	X(14)	= 73.8500000	X(15)	= 4.81300000	X(16)	= .555000000E-16
X(17)	= .374000000E-01	X(18)	= 15.1900000	X(19)	= 10.9700000	X(20)	= 13.4290000
X(21)	= 33.2800000	X(22)	= 78.1300000	X(25)	= 7.50000000	X(26)	= 4.10000000
X(37)	= 0	X(38)	= .124900000E-01	X(62)	= 6.19700000	X(64)	= 0
X(98)	= 0	X(99)	= 0				

TIME = 222.000000

X(1)	= 0	X(2)	= 0	X(3)	= 1841.43324	X(4)	= 9970.00000
X(5)	= 11896.0000	X(6)	= .363797881E-11	X(7)	= 22.7029225	X(8)	= 0
X(9)	= 30.0122344	X(10)	= 1.44617946	X(11)	= 4.36946003	X(12)	= 17.2453675
X(13)	= 266.303294	X(14)	= 73.8649028	X(15)	= 4.53885425	X(16)	= .742216337E-02
X(17)	= .962492764E-01	X(18)	= 14.8747476	X(19)	= 10.4795804	X(20)	= 12.9296365
X(21)	= 33.5421234	X(22)	= 78.1803604	X(25)	= .694649515E-03	X(26)	= 1.50044285
X(37)	= 0	X(38)	= .121730043E-01	X(62)	= 6.71313395	X(64)	= .229816166E-13
X(98)	= 0	X(99)	= 1227.09818				

TIME = 313.000000

X(1)	= 0	X(2)	= 167.714134	X(3)	= 2254.90420	X(4)	= 9970.00000
X(5)	= 11896.0000	X(6)	= .920863386E-11	X(7)	= 89.8820373	X(8)	= 0
X(9)	= 31.2160967	X(10)	= .707015267E-14	X(11)	= 5.10422716	X(12)	= 13.8859459
X(13)	= 268.730964	X(14)	= 73.5880364	X(15)	= 4.02130099	X(16)	= .124134200E-01
X(17)	= .946402078E-01	X(18)	= 15.2302701	X(19)	= 11.1589747	X(20)	= 13.0365878
X(21)	= 33.5341270	X(22)	= 78.1916212	X(25)	= 3.00000000	X(26)	= .381436040
X(37)	= 5.28639731	X(38)	= 0	X(62)	= 7.57508395	X(64)	= .262567745E-13
X(98)	= 0	X(99)	= 570.802700				

TIME = 404.000000

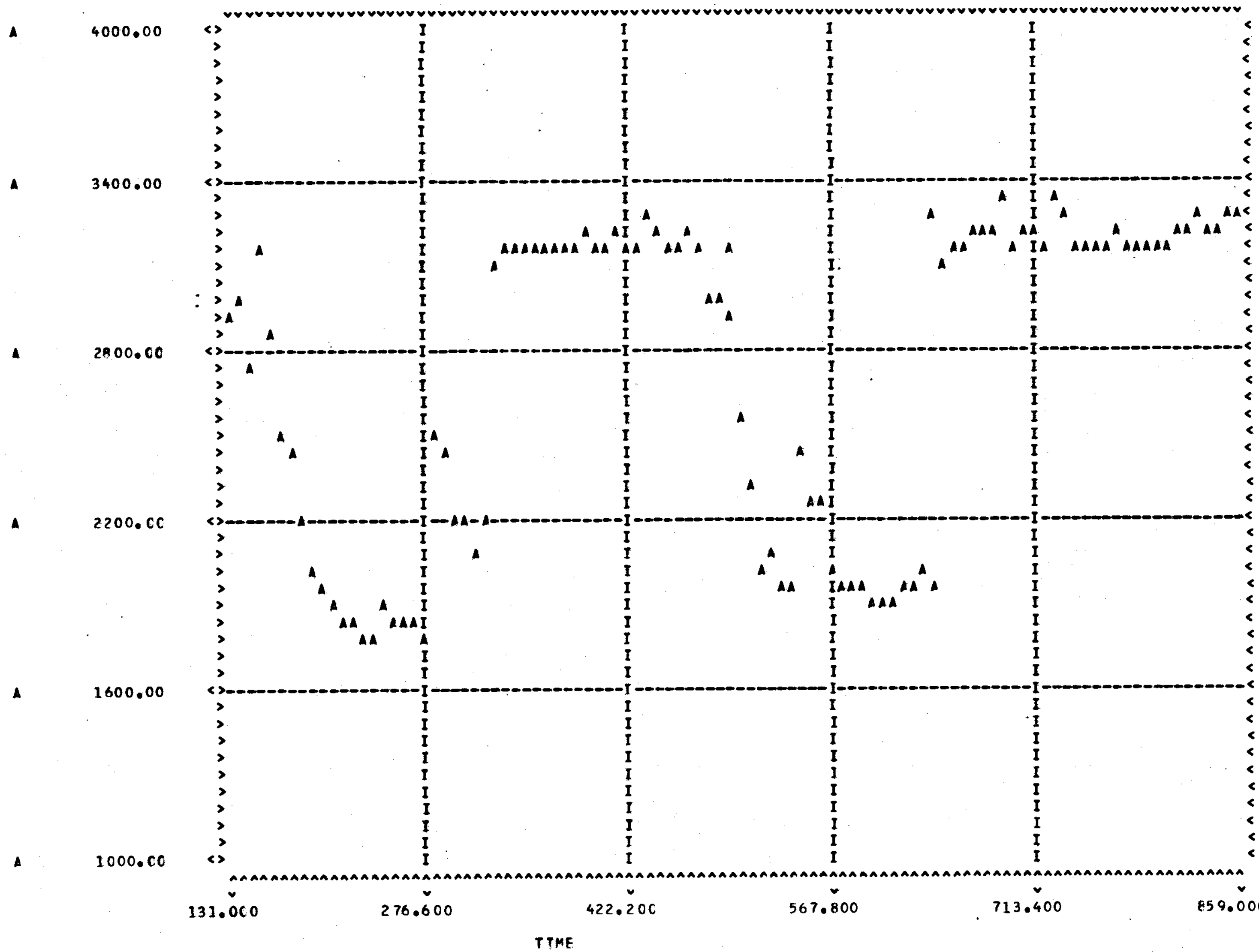
X(1)	= 4.31610044	X(2)	= 3458.70476	X(3)	= 3198.32464	X(4)	= 9970.00606
X(5)	= 11896.0118	X(6)	= .165201186E-10	X(7)	= 83.3956334	X(8)	= 2.07915555
X(9)	= 32.2834545	X(10)	= .704115658E-14	X(11)	= 4.73932044	X(12)	= 12.5308779
X(13)	= 267.173550	X(14)	= 73.3203509	X(15)	= 3.75800840	X(16)	= .124097779E-01
X(17)	= .521102855E-01	X(18)	= 14.3350700	X(19)	= 10.2519884	X(20)	= 12.1412108
X(21)	= 34.1035847	X(22)	= 78.2108005	X(25)	= 3.00000000	X(26)	= 1.81694614
X(37)	= 6.57576546	X(38)	= 0	X(62)	= 8.11842884	X(64)	= .262567745E-13
X(98)	= .568434189E-13	X(99)	= -3661.91082				

```
TIME =   495.000000
    X(1)        =            0     X(2)        =            0     X(3)        =  2969.85168     X(4)        =  9970.00514
    X(5)        =  11896.0100      X(6)        =  .190212290E-10  X(7)        =  66.9085529     X(8)        =            0
    X(9)        =  33.3219423      X(10)       =  .289307755      X(11)       =  4.55193666     X(12)       =  23.3512491
    X(13)       =  265.950498      X(14)       =  73.2155002      X(15)       =  3.74726154     X(16)       =  .353805832E-03
    X(17)       =  .389754578E-01  X(18)       =  13.3845538      X(19)       =  9.15924438     X(20)       =  11.1903358
    X(21)       =  34.6851862      X(22)       =  78.2583196      X(25)       =  .710327303E-01 X(26)       =  1.86821824
    X(37)       =            0     X(38)       =  .124026930E-01  X(62)       =  8.26561535     X(64)       =  .251666870E-13
    X(98)       =            0     X(99)       =  49.2139045

TIME =   586.000000
    X(1)        =            0     X(2)        =            0     X(3)        =  1952.31998     X(4)        =  9970.00000
    X(5)        =  11896.0000      X(6)        =  .241655584E-10  X(7)        =  47.8383254     X(8)        =            0
    X(9)        =  34.5235370      X(10)       =  1.43471657      X(11)       =  4.36791119     X(12)       =  24.6018877
    X(13)       =  271.163053      X(14)       =  72.9910919      X(15)       =  3.54367416     X(16)       =  .745820541E-02
    X(17)       =  .101238205      X(18)       =  13.7352057      X(19)       =  9.32920289     X(20)       =  11.2654248
    X(21)       =  34.6831546      X(22)       =  78.2745505      X(25)       =  .615498980E-05 X(26)       =  .479313856
    X(37)       =            0     X(38)       =  .121060645E-01  X(62)       =  8.77412719     X(64)       =  .533663519E-13
    X(98)       =            0     X(99)       =  1077.90523

TIME =   677.000000
    X(1)        =  7.31272385      X(2)        =            0     X(3)        =  3270.31394     X(4)        =  10029.0936
    X(5)        =  11935.6177      X(6)        =  .355093732E-10  X(7)        =  82.0091628     X(8)        =  5.69195357
    X(9)        =  35.7500407      X(10)       =  .706568073E-14  X(11)       =  5.09552074     X(12)       =  18.0068865
    X(13)       =  273.942950      X(14)       =  72.6571625      X(15)       =  3.26296398     X(16)       =  .122909023E-01
    X(17)       =  .107645245      X(18)       =  14.0974371      X(19)       =  10.0080215     X(20)       =  11.3782118
    X(21)       =  34.6833785      X(22)       =  78.2789114      X(25)       =  .229141021E-09 X(26)       =  .121835538
    X(37)       =            0     X(38)       =            0     X(62)       =  9.40314662     X(64)       =  .555312868E-13
    X(98)       =            0     X(99)       = -383.494287

TIME =   768.000000
    X(1)        =  13.5972089      X(2)        =  3241.03940      X(3)        =  3265.20675     X(4)        =  10071.6324
    X(5)        =  12005.7963      X(6)        =  .364543951E-10  X(7)        =  88.6804969     X(8)        =  9.58365637
    X(9)        =  36.7635494      X(10)       =  .704358313E-14  X(11)       =  4.73157068     X(12)       =  16.2722171
    X(13)       =  272.355330      X(14)       =  72.4353026      X(15)       =  3.16716823     X(16)       =  .122881532E-01
    X(17)       =  .587662228E-01  X(18)       =  12.9843557      X(19)       =  8.92378985     X(20)       =  10.4592721
    X(21)       =  35.3347723      X(22)       =  78.3051273      X(25)       =  3.00000000     X(26)       =  2.18368035
    X(37)       =            0     X(38)       =            0     X(62)       =  9.70534330     X(64)       =  .555312868E-13
    X(98)       =  130.297135      X(99)       = -3879.17468

TIME =   859.000000
    X(1)        =            0     X(2)        =  73.8357538      X(3)        =  3338.04473     X(4)        =  10191.1253
    X(5)        =  12117.7018      X(6)        =  .364543951E-10  X(7)        =  100.321319     X(8)        =            0
    X(9)        =  37.7462478      X(10)       =  .266142424      X(11)       =  4.54517400     X(12)       =  22.4242697
    X(13)       =  271.076654      X(14)       =  72.3779005      X(15)       =  3.19069272     X(16)       =  .327536624E-03
    X(17)       =  .407721632E-01  X(18)       =  11.9068106      X(19)       =  7.76170738     X(20)       =  9.53957168
    X(21)       =  35.9737131      X(22)       =  78.3621672      X(25)       =  3.00000000     X(26)       =  2.79250250
    X(37)       =            0     X(38)       =  .122828713E-01  X(62)       =  9.69737739     X(64)       =  .554400648E-13
    X(98)       =  16.4660874      X(99)       = -894.858077
```

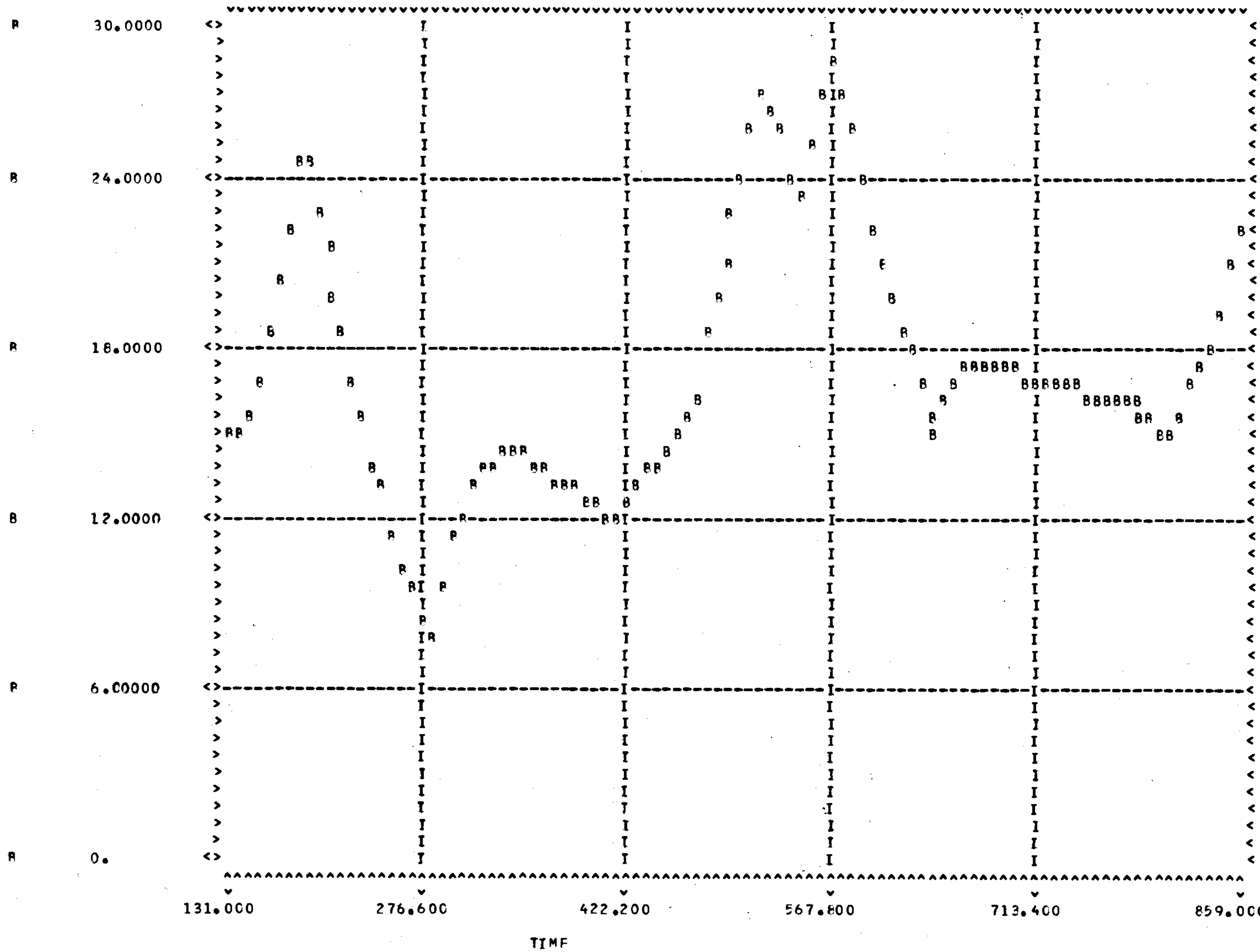
GRAPHICAL SIMULATION RESULTS

GRAPH NO.	GROUP NO.	INDEPENDENT VARIABLE	DEPENDENT VARIABLE(S)	PLOTTED CHARACTER
1	1	TIME	X(3)	A
2	1	TIME	X(12)	B

GRAPH NO. 1


A 4000.00
A 3400.00
A 2800.00
A 2200.00
A 1600.00
A 1000.00
131.000
276.600
422.200
567.800
713.400
859.000
TIME

GRAPH NO. 2


B 30.0000
B 24.0000
B 18.0000
B 12.0000
B 6.00000
B 0.
131.000
276.600
422.200
567.800
713.400
859.000
TIME