Appendix VII. Forest Model Coding

"Woodstock" Formulation

Overview Of Forest Modeling Structure

Description	Woodstock Input Files
Model Control	Control File (objectives, planning horizon, period length)
Landbase Themes	Landscape File (aggregation of polygon attribute into themes
Area Netdown	Areas File (aggregation of areas in accordance with defined themes
Forest Growth	Yields File (merchantable volume yield equations)
Activities	Actions File (harvest, death and associated constraints)
Succession	Transitions File (changes to area attributes resulting from specific actions)
Outputs	Output Reports and Graphics (model results)

Woodstock Model Formulation[1]

Landscape Section

Landscape themes describe a variety of Characteristics about the forest. They are analogous to different map layers in a GIS system or stand attributes in a database. Themes are numbered sequentially and denoted with a descriptive label indicating its purpose or nature. For a given landscape theme, there can be many attributes attached that describe the various conditions or site attributes found throughout the forest. The database upon which the themes are constructed rely heavily on GIS to encode polygons with spatial attributes (steep slopes, buffers, protected areas) developed through layering and the database netdown process.

For example, the polygons within the FLI database contain species composition. Using this data and an algorithm that aggregates species composition into strata types, a new field is defined, and each polygon is populated with the resulting strata type code. This code is then listed under a landscape theme. There are 10 different strata type codes. You may also describe a forest condition that is based on an aggregate of theme attributes. For example, by combining forest strata codes 1 (PTA) and 2 (MDE) into an aggregate coded hwstands, all hardwood strata are identified.

To refer to polygons or areas of interest within the forest, you do so by specifying a landscape theme "mask" which is simply a line of code representing the sequence of themes (theme 1, theme 2, theme 3, …). The attribute code appropriately placed on the theme mask will identify (filter) the desired information from the data set. When you use a question mark (?) as a thematic attribute code, all attribute codes within that theme are represented. For example, the following mask identifies a development type that includes all hardwood polygons in protected areas (code 17 in theme 5) (? ? hwstands ? 17 ? ?) In this analysis there are 7 themes as follows:

***THEME** theme 1 land status code as per 1998 MB Forest Inventory Field Instructions Manual

0	; agriculture
1	; provincial forest
2	; permanent forest
3	; national park
4	; wildlife management area
5	; FML
6	; specified area
7	; provincial park
8	; INCO land
9	; other land
41	; joint wildlife management area and provincial forest
17	; joint provincial forest and provincial park

***AGGREGATE** 11 Provincial forests
1 2 4 5 7 17 41

***AGGREGATE** 10 Non-Provincial forests
0 3 6 8 9

[1] the informational text in this appendix has been paraphrased from "Woodstock and the Woodstock User's Guide, Copyright Remsoft Inc. 1998

***THEME** theme 2 land ownership Code

0 ; Prov. crown land closed
1 ; Prov. crown land open
2 ; Prov. crown land restricted
3 ; Federal land
4 ; Municipal land
5 ; Patent land
6 ; L.G.D. land
7 ; I. R.
8 ; T.L.E.
9 ; other

***THEME** theme 3 Yield Curve ID Code

0 ; non forest
1 ; PTA (80%+ Trembling Aspen)
2 ; MDE (mixed deciduous)
3 ; PJP (80%+ Jack Pine)
4 ; UBS (80%+ upland Black Spruce)
5 ; LBS (80%+ lowland Black Spruce)
6 ; PWS (80%+ White Spruce/Fir)
7 ; MWS (Softwood dominant mixedwood)
8 ; NWS (hardwood dominant mixedwood)
9 ; MBS (Black Spruce/Tamarack dominant mixedwood)
10 ; NBS (Hardwood dominating Black Spruce/Tamarack)
11 ; Pure hardwood from transitions section

***AGGREGATE** swstands
3 4 5 6

***AGGREGATE** mxstands
7 9

***AGGREGATE** nxstands
8 10

***AGGREGATE** hwstands
1 2

***THEME** theme 4 ;Crown Closure (density) Code
0 ; non-forested
1 ; 1-10% crown closure
2 ; 11-20% crown closure
3 ; 21-30 % crown closure
4 ; 31-40% crown closure
5 ; 41-50% crown closure
6 ; 51-60% crown closure
7 ; 61-70% crown closure
8 ; 71-80% crown closure
9 ; 81-90% crown closure
10 ; 91-100% crown closure

***AGGREGATE** 11 open <=50% crown closure
1 2 3 4 5

***AGGREGATE** 12 closed >50% crown closure
6 7 8 9 10

***AGGREGATE** 13 moderate 51-70% closure for wildlife cover
6 7

***AGGREGATE** 14 high 71-80% closure for wildlife cover
8 9 10

***THEME** theme 5 Forest Stand Status Codes
0
11 ; nat (natural stand)
12 ; BO (burn-over)
13 ; CO (cut-over)
14 ; regen (regenerating stand)
15 ; nsr (not satisfactorily regenerating)
16 ; nf (non-forested productive area)
19 ; steep slope >=41%
20 ; riverbuffer
21 ; lakebuffer
22 ; roadbuffer
23 ; heritagesitebuff (50m)
24 ; proposed ecoreserve
25 ; TLE selection
190 ; selected steep slope
192 ; bell B
193 ; steeprock A
195 ; canyon core

***AGGREGATE** 1 Harvestable stands
11 12 13 14

***AGGREGATE** 2 Non-harvestable stands
15 16 19 20 21 22 23 24 25 190 192 193 195

***THEME** theme 6 FMU (forest management unit ID)
13
14

***THEME** theme 7 Available for use

Lifespan Section

The lifespan specification indicates the maximum age a yield stratum may reach before it is assumed to die or be replaced by another development type through succession. In this analysis a lifespan is specified for every yield strata present in the forest as per the following development masks.

The _DEATH function in the TRANSITIONS section determines the outcome of the development type in the case of death.

;lifespan

```
? ? swstands  ? 15  ? ?   1          ; nsr(code15) softwood stands receive
                                       a 1 period regen delay
? ? mxstands  ? 15  ? ?   1          ; nsr(code15) softwood mixes receive
                                       a 1 period regen delay

? ? ? ? 12  ? ?    2                 ; burns receive a 2-period regen lag
? ? 1 ? ?   ? ?   28                 ; yield strata 1 (PTA) dies at 28
                                       periods (140 years)
? ? 2 ? ?   ? ?   30
? ? 3 ? ?   ? ?   32
? ? 4 ? ?   ? ?   36
? ? 5 ? ?   ? ?   36
? ? 6 ? ?   ? ?   30
? ? 7 ? ?   ? ?   30
? ? 8 ? ?   ? ?   30
? ? 9 ? ?   ? ?   32
? ? 10 ? ?  ? ?   32
? ? 11 ? ?  ? ?   28
? ? 0 0 0   ? ?   40                 ; all others die at 40 periods
```

Areas Section

The areas section is where you define the development types that populate your forest. A development type is simply a portion of your forest database that is defined or redefined by a particular set of landscape theme attributes: each unique combination of thematic attributes represents a different development type. The areas section input file (area file) is a product of the attribute layering and GIS netdown work on the forest landbase. The area database and attributes of interest are organized into associated age classes and restructured to match the fields of the thematic mask presented in the themes section. The main purpose of this file is to:

a) describe the existing forest in terms of landscape themes and attribute codes,
b) provide an age-class structure of the existing forest,
c) detail the distribution of area associated with development types across the forest, and to
d) provide a means of recognizing discrete portions of the forest within a stratum based forest model.

```
*A  5  1  1  1  11  13  1  4  8.69629      ;for this combination of theme codes there are 8.69629
                                             hectares in the period 4 (20 year) age class.
*A  5  1  1  1  11  13  1  5  37.73948
*A  5  1  1  1  11  13  1  6  2.82463
*A  5  1  1  1  11  13  1  7  1.77335
*A  5  1  1  1  11  13  1  9  4.78756
*A  5  1  1  1  11  13  1  10  1.67897
*A  5  1  1  1  11  13  1  11  2.14807
*A  5  1  1  1  11  13  1  12  2.14147
*A  5  1  1  1  11  13  1  13  11.40457
*A  5  1  1  1  11  13  1  14  9.38044
*A  5  1  1  1  11  13  1  16  1.50256
```

Yields Section

The yields section is the part of a Woodstock model where you associate things like stand volumes with the development types in the model. Whereas landscape themes describe the landbase in static terms (attributes that remain the same over time), the yield tables provide dynamic information about the forest. The yields section contains the growth information needed to move the model forward in time.

In this model, the yield components represent two characteristics of interest: volume and habitat indices. Both are age dependent, with the value of the component varying with the age of the development type.

The yield tables used in the model are based on periods rather than years. Yield table entries represent 5-year intervals.

The thematic attribute masks are used to locate sets of yield tables associated with the development types as follows:

***Y** ? ? 5 ? ? ? ? ;yield curve mask for lowland Black Spruce (code 5)

soft 1 0.39 1.56 3.39 5.75 8.52 11.59 14.86 18.25 21.70 25.12 28.49 31.74 34.51 38.22 41.04 44.32 47.56 49.99 53.02 55.56 56.77 56.87 56.76 56.50 55.54 53.22 49.87 46.62 43.33 39.84 36.2 30.31 24.74 18.24 12.12 7.45 3.21 2.34 1.12

hard 1 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.1 0.2 0.3 0.4 0.5 0.7 0.9 0.10 0.12 0.15 0.18 0.22 0……..etc

swhw soft + hard

The thematic attribute masks used to locate habitat yield tables associated with the development types are as follows:

***Y** ? ? 1 11 ? ? ?
elkcover 0 0 0.1 0.2 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.4 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5

elkfood 0 0.8 0.8 0.7 0.7 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6

***Y** ? ? 1 11 ? ? ?
moosecover 0 0 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1

moosefood 0 0.3 1 11 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6
…….etc.

Actions Section

This section provides the mechanism for effecting changes in the model. Without defining actions, development types within the model would just grow older and eventually die. Woodstock models need interventions defined by the user such as silvicultural treatment or harvesting. The only inherent activities Woodstock can perform are death and inventory - the user must define all others.

The outcomes of actions are not part of the ACTIONS section, but are specified in another section (TRANSITIONS). In a Woodstock model, actions are defined by three parameters:

a) whether the development type arising from the action is assumed to have an age different from the pre-treatment development type from which it originated.
b) the circumstances in which the action may be applied (eligibility or operability windows),
c) whether outputs arising from the action should be a direct function of yield components and area treated, or as a function of area treated and the difference between pre-treatment and post-treatment yield components (complete harvest or partial harvest).

This model's action file is as follows:

```
*ACTION          clct  y     diameter cut          ; clearcut harvest with age reset to 0

*OPERABLE  clct
11   1   5   ?   1   ?   ?  soft >= 950 and _AGE >= 13     ; the high soft volume constraint  is to
                                                            prevent harvesting LBS stratum
11   1   1   ?   1   ?   ?  hard >= 75 and _AGE >= 12
11   1   2   ?   1   ?   ?  hard >= 75 and _AGE >= 10
11   1   3   ?   1   ?   ?  soft >= 50  and _AGE >= 13
11   1   4  11   1   ?   ?  soft >= 50 and _AGE >= 14
11   1   4  12   1   ?   ?  soft >= 50 and _AGE >= 11
11   1   6  11   1   ?   ?  soft >= 50 and _AGE >= 14
11   1   6  12   1   ?   ?  soft >= 50 and _AGE >= 15
11   1   7   ?   1   ?   ?  soft >= 50 and _AGE >= 11
11   1   8   ?   1   ?   ?  hard >= 75 and _AGE >= 12
11   1   9   ?   1   ?   ?  soft >= 50 and _AGE >= 14
11   1  10   ?   1   ?   ?  hard >= 75 and _AGE >= 14
11   1  11   ?   1   ?   ?  hard >= 75 and _AGE >= 12
```

Transitions Section

The transition section is key to forest dynamics in a Woodstock model. Transition specifications describe how the forest will respond to actions or events in terms of forest development represented using landscape themes. Transitions are specific in terms of source and target so it is possible to model complex management prescriptions or outcomes of actions.

The transition section also provides a means for restricting access to development types following an action or prevents any actions from occurring on a target development type for a specified number of periods following the action.

The transitions section allows the user to:

a) document the changes that areas of the forest undergo following an action,
b) represent forest dynamics in the form of a transition matrix,
c) provide a mechanism for restricting access to development types following treatment and
d) provide a mechanism for changing the default age of development types arising out of an action.

The Transitions used in this model are coded as follows:

```
;Transitions
*CASE  clct                                ;result of clearcut action (see actions section)

*SOURCE  ?  ?  hwstands   4  ?  ?  ?  ;when action clearcuts density class 4 hwstands
                                           (aggregate)
*TARGET  ?  ?  11  6  ?  ?  ?  100  ;100% of hectares return statum 11 density
                                           class 6

*SOURCE  ?  ?  8  ?  ?  ?  ?          ;  when action clearcuts strata 8
*TARGET  ?  ?  8  ?  ?  ?  ?   50     ; 50% of hectares harvested return as strata 8
*TARGET  ?  ?  1  ?  ?  ?  ?   50     ; 50% of hectares harvested return as strata 1
        .
        .
        .
        .

*CASE   _DEATH                         ;When death occurs due to lifespan

*SOURCE   ?  ?  ?  ?  12  ?  ?         ;following a 2 period lifespan burned hectare(12)
*TARGET   ?  ?  ?  ?  11  ?  ?  100    ; return to natural (11) forest state

*SOURCE   ?  ?  ?  ?  15  ?  ?         ; following a 1 period lifespan, nsr(15) hectares
*TARGET   ?  ?  ?  ?  14  ?  ?  100    ; return to regenerating (14) forest state

*SOURCE   ?  ?  ?  ?  11  ?  ?         ; upon reaching their lifespan development types in
*TARGET   ?  ?  ?  ?  11  ?  ?  100    ; the nat (11) forest state remain in natural state
```

***SOURCE** ? ? ? ? 14 ? ? ; upon reaching their lifespan development types in
***TARGET** ? ? ? ? 11 ? ? 100 ; in the regen (14) state return to the nat (11) state

***SOURCE** ? ? ? ? ? ? ? ;all other development types return to same type
***TARGET** ? ? ? ? ? ? ? 100 ; after death

Outputs Section

The output section calculates the various measures of interest such as total softwood harvest or area harvested. All outputs are triggered by actions and a function of a per unit area estimate in a yield table multiplied by the area effected by the triggering action. Outputs are the basis for evaluating a management regime, and the levels of output produced are used to control activities across the forest and across the planning periods.

The objective function (maximize volume) can be composed of one or more outputs (total softwood harvest + total hardwood harvest). Constraints such as minimum age or minimum volume/ha can be established on various outputs as well. Almost any output defined can be part of an objective function or constraint.

The output section provides:

a) a means of reporting on benefits and/or costs arising from actions as well as areas affected by them.
b) provides a mechanism for controlling actions by limiting production of one or more outputs.
c) provides a basis for comparison among different management strategies.

Examples of outputs for this model are as follows:

```
*OUTPUT  lrsy    lrsy
  *SOURCE  11  2  ?  ?  1  ?  ?   _INVENT  tmai

*OUTPUT  swgstock     sw  growing  stock
  *SOURCE  11  1  ?  ?  1  ?  ?   _INVENT  soft

*OUTPUT  hwgstock      hw growing stock
  *SOURCE  11  1  ?  ?  1  ?  ?   _INVENT  hard

*OUTPUT  gstock      growing stock
  *SOURCE  swgstock + hwgstock

*OUTPUT  opstock     total operatble stock
  *SOURCE  11  1  ?  ?  1  ?  ?  _INVENT (clct)  soft  +
           11  1  ?  ?  1  ?  ?  _INVENT (clct)  hard
```

.
.
.
.
.
.

Optimize Section

This section is used to formulate the model as a linear program, which requires a different viewpoint than, is required with simulation models. In a simulation model, the user decides what prescriptions to implement, determine what order to implement them in and review the outcome as the simulator executes the model. In a linear programming model, the user decides the kind of outcome desired and the model determines the best means of accomplishing that objective.

Objective Functions

In this section the objective function is presented. In this model the objective function maximizes the amount of wood harvested from the forest by summing the outputs of interest. The Woodstock interpreter uses the output definitions to formulate the objective function as the sum of all decision variables that generate harvest volume multiplied by the appropriate yield entries. In defining an objective function not only do you specify the outputs you want but also the time interval when the specified outputs will contribute to the objective function. In this model the maximization occurs over the 200 year planning horizon.

Constraints

Harvest flow constraints are typically used to control the flow of outputs on a period by period basis. For example, non-declining yield would allow the harvest level to increase or remain at the previous period level over the planning horizon, but the harvest level could not decrease. Strict even-flow would force the harvest to remain constant throughout the planning horizon and a sequential flow would allow the harvest to fluctuate by a fixed or proportional amount each period.

The model is optimized under the following objective and constraint formulation:

```
; Optimize

*OBJECTIVE
        _MAX  shvol   1.. _LENGTH


*CONSTRAINTS
        _EVEN (swvol)    1.. _LENGTH
        _EVEN (hwvol)    1.. _LENGTH


        _NDY (shvolopstock)   (#PH-9).. _LENGTH


*FORMAT    XA
```

Schedule Section

This section is created by the linear program solver, which present to Woodstock the optimal solution through a solution file. Woodstock processes that solution file and creates a management schedule file. The management schedule file is then included with the other sections of the Woodstock model. The Woodstock model carries out the actions selected in the optimal solution, allowing the creation of reports and graphics.

The SCHEDULE section is simply a listing of actions performed on specific **hectares** associated with specific **age classes** within development types in **each planning period**. Each line is the SCHEDULE section represents one decision variable and so a development type mask, age, area, action code and planning period will be listed.

The first few lines of the model schedule is presented as follows:

```
-development mask--   age    hectares  action   period
5   1   1   1   11  13   1     18    71.7095   clct     1        _EXISTING  ;A1706  100.0% of class
5   1   1  10   11  13   1     21   210.5780   clct     1        _EXISTING  ;A1706  40.5% of class
```

Control Section

The control section is where the parameters used to execute Woodstock forest model are specified. Beyond establishing the planning horizon for the model the control section keywords allow image file activation and warning message controls. In this model, OPTIMIZE is set to on, generating a linear programming matrix in the format specified in the OPTIMIZE section. The linear programming matrix is then passed to the linear programming solver software to find an optimal solution. The solver generates a file that details which of the decision variables were selected in the optimal solution. A utility program to convert a solution file to a management schedule file is included in Woodstock. This file uses the format for the SCHEDULE section, and is processed by the Woodstock interpreter. If reports and graphics are defined, the interpreter will create report files and display graphics as the schedule file is processed.

Model formulation example:

; Control

***LENGTH** 40 (5 yr periods)
***REPORTS** ON
***GRAPHICS** ON
***QUEUE** OFF
***OPTIMIZE** ON
  ***SCHEDULE** ON
  ***WARNINGS** ON
  ***IMAGE** ON
  ***BUILD** ON
  ***DEBUG** ON
  ***LPSCHEDULE** OFF

Reports Section

The report section specifies the outputs that are to be reported numerically, in several formats and is completely customizable. This model generates reports of all outputs on a period to period basis.

The reports provide:

a) a mechanism for evaluating management strategies by reporting outputs generated by a Woodstock model run,
b) custom reports that are helpful in testing and debugging models
c) user-definable reports in ASCII text format that can be read directly and/or imported into other software for additional analysis and generation of high quality graphs.

An example of the formulation of the reports section is as follows:

```
;  Reports

; all outputs in spreadsheet format

*TARGET  bigmama.wk1   _FORM2
_ALL    0.. _LENGTH

*TARGET  operable1.wk1
_OPERABLE (_DEATH,harvest)  1.. _LENGTH

*TARGET  info1.wk1
areakilled  1.. _LENGTH
avharage * 5   1.. _LENGTH
ccarea     1.. _LENGTH

*TARGET    FMU13_SWHWOPSTOCK_NDY.WK1
swgstock         0.. _LENGTH
hwgstock         0.. _LENGTH
gstock           0.. _LENGTH
swopstock        0.. _LENGTH
hwopstock        0.. _LENGTH
opstock          0.. _LENGTH
.
.
.
.
```

Graphics Section

In order to visualize changes in the forest overtime, optional graphics of outputs are plotted over time; providing a mechanism for graphically displaying output levels in real time.

The formulation in this section is as follows.

```
; Graphics
*SCREENSIZE MAXIMIZED
*FONT1 "SYSTEM" 8   0   1000
*FONT2 "SYSTEM" 8   0   1000

*WINDOW (   0,   163,   480,   350) "Fig. 1.2  Harvest Volume (000's) over 200 years
  _LEGEND (488, 130)
  _YAXIS (*,*,*)

*LINES
title   1   5000    _WHITE   _NONE   _SOLID
lrsy   1   1000   _RED   _NONE   _DOTTED   "LRSY"
shvol   1   5000   _RED   _NONE   _SOLID   "Total Harvest Volume/yr"
swvol   1   5000  _GREEN   _CIRCLE    _SOLID   "SW Harvest Volume/yr"
hwvol   1   5000  _BLUE   _SQUARE   _SOLID   "HW Harvest Volume/yr"
.
.
.
.
.
```