FVS-BGC:
User's Guide to Version 1.1
(unofficial release)

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ABSTRACT

FVS-BGC is an adaptation of the Stand-BGC (Bio-Geochemical Cycles) model for use with the Forest Service's Forest Vegetation Simulator (FVS) software. Stand-BGC is an eco-physiology process model which emphasizes site and plant water balance. FVS-BGC operates as an FVS extension. Stand information, simulated stand management operations, and standard FVS outputs are provided by FVS shell in which FVS-BGC operates. Site conditions and weather scenarios are provided as input within FVS-BGC. FVS-BGC simulates photosynthetic production daily and allocates this production as plant growth annually. Projections at the end of the FVS multi-year simulation cycle are available for both the standard FVS growth equations and the FVS-BGC process model. Either may be used as the starting conditions for future projections. This document provides basic instructions in how to run the FVS-BGC software.

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SUMMARY

FVS-BGC is an adaptation of the Stand-BGC model (Milner and Coble 1995) to function as an extension of the Forest Vegetation Simulator (FVS) system (Wykoff et al. 1982, Dixon 2002). Unlike the empirically derived growth algorithms within FVS, growth in Stand-BGC is process-driven: climate data drive growth, which reflects tree competition for light and water resources. This new extension—FVS-BGC—provides a suite of carbon- and water-cycle output files at the tree and stand levels, at both daily and yearly time steps, as well as standard FVS stand tables derived from the process model.

The primary purpose of this guide is to provide model users with information regarding the mechanics of running the computer programs associated with FVS-BGC. Included are details about preparing input files, interpreting output files, and using the FVS-BGC keywords. Users unfamiliar with the fundamentals of running FVS should consult relevant documents included in the reference section. References relating to Stand-BGC and related models are also included. These provide the scientific bases and mathematical details of the primary model elements of FVS-BGC.

FVS-BGC was developed using the North Idaho variant of FVS. Currently the model accommodates all coniferous species recognized by the following western variants of FVS: Blue Mountains, Central Idaho, Central Rockies, Eastside Cascades, Eastern Montana, Kootenai, North Idaho, Tetons, and Utah.

As with other FVS extensions, a user invokes FVS-BGC via keywords. Three external files must be present to run the extension: a daily climate file and two files that supply physiological, site, and control parameters. Under-story vegetation (shrubs and grasses) may be entered via FVS-BGC keywords or generated by running the COVER extension of FVS (Moeur 1985). All vegetation (trees, shrubs, and grasses) is grown in FVS-BGC and competes for site water and light resources. Thus, FVS-BGC tree increments, particularly for small trees, may be sensitive to amounts of under-story vegetation.

Trees in FVS-BGC are initialized by the FVS tree list at the beginning of the simulation, and updated by FVS at the beginning of each subsequent cycle. How the updating takes place depends upon which of two “modes” the extension is run. FVS will project tree growth and mortality using either: (1) FVS-BGC’s projected growth increments, or (2) FVS’s own projected growth increments (the increments it would normally use). The user defines—via keyword—whether FVS-BGC will drive tree growth in FVS or whether FVS tree growth will drive FVS-BGC.

If the FVS-BGC-projected growth and mortality estimates are used within FVS (mode 1), then at FVS cycle boundaries, FVS’ projections are overwritten by FVS-BGC’s projections for that growth cycle. Any mortality or growth effects arising from insect or disease extensions of FVS will be ignored (within both FVS and FVS-BGC). However, all FVS-simulated management actions (e.g., thinnings, plantings) and/or regeneration will be imposed in both models, and is imposed within FVS-BGC when FVS-BGC’s tree list is updated at the beginning of each cycle.

In the second mode, normal FVS-projected growth and mortality projections are used, as if FVS-BGC is not running at all. In this mode, FVS-BGC runs “in parallel” with FVS, and still provides an estimate of within-cycle growth and biogeochemical processes (water

and carbon balances, etc.). However, FVS-BGC is completely reinitialized by FVS at the beginning of each cycle. No BGC-projected growth increments are passed to FVS, and any end-of-cycle projections within FVS-BGC are completely over-written at the beginning of each cycle with FVS' updated tree list.

FVS-BGC output currently consists of: (1) tabular presentations of the annual and daily predictions of stand- and entity-level carbon and water balances, and annual entity-level growth increments, (2) a mortality table showing when specific trees die, along with selected attributes, and (3) a table showing the daily site water balance for each year of the simulation.

Initial inspection suggests that the physiological output from FVS-BGC is reasonable, at least insofar as it provides for tree and stand growth similar to that generated from FVS alone. Thus, there is cautious optimism that this "process" extension might provide useful information for a variety of purposes. It might be useful to test the sensitivity of current growth and mortality equations to variation in climate patterns and increased CO_2 levels. It could provide a method of linking stand conditions and forest management alternatives to eco-physiology conditions, such as below canopy light levels, carbon balances, and water use. It has the potential to disaggregate the factors that determine site index. It can provide physiology modelers with a linkage to the extensive "real world" growth information incorporated in the base FVS growth equations. For forest health issues, such as the relationship between moisture stress and pest susceptibility, the model can simulate the tradeoffs between stand density and precipitation conditions.

Addendum pertaining to this (unofficial) Version 1.1 release

A number of updates have been coded into this new Version 1.1. These are outlined in Appendix F. Also, three heretofore unused *Beta.dat* file parameters are now being used for new functions. These are also described in Appendix F, and are acknowledged in Tables 6 and 7. Finally, a few minor corrections to the body of this document's text have been made.

Regarding the usage of the term "FVS-BGC" in this document.

The authors now encourage the use of the term "FVS-BGC" to refer to the entire "package" of base-FVS combined with the Stand-BGC, rather than the convention used throughout this document, where "FVS-BGC" refers to the Stand-BGC portion of the model. So, when reading this document, think "BGC portion" of the FVS-BGC model when you encounter the term "FVS-BGC".

Andrew McMahan. July 28, 2006. Fort Collins, CO

1: INTRODUCTION

1.1 FVS meets Stand-BGC: A hybrid approach to forest growth simulation[1]

The USDA Forest Service's Forest Vegetation Simulator (FVS) system is a well supported, well-established software package for simulating the effects of growth, mortality, and management on forest stands in the United States. It has also been adapted for use in other countries. At its core is a set of localized growth equations, based on extensive field measurements. Its origin was in timber management oriented models such as Prognosis (ref), whose primary purpose was to predict the future growth and yield of timber available from forest stands. These models were therefore designed to use input available from standard timber inventory surveys, and to provide output that focused on the harvestable portion of the trees' stems. FVS has evolved to address a wider array of forest management issues, but its orientation towards projecting stem size and number remain.

Forest management has shifted its perception of a forest from a commodities production system to a life support system. As a consequence, there has been significant interest focused on developing and evaluating process-based models (PBMs) for inclusion in the analytic toolbox available to forest managers and analysts. In addition to traditional timber-oriented outputs, these professionals need a suite of ecosystem process attributes to better understand how forest ecosystems function. For example, appropriate PBMs could permit exploration of the effects of proposed silvicultural treatments on stand-level water, carbon, and nutrient cycles. Such output could in turn be used to generate mechanistic indexes of ecosystem health that could augment the pattern-dominated indices currently in use. Because PBMs are generally climate-driven, such indices would be climate-sensitive and thus would support the calculation of climate-dependent risk factors for alternative conditions scenarios. Generally, PBMs could be useful in assessing weather and climate effects on vegetation dynamics, and could provide climate-sensitive physiological variables useful in enhancing linkages to forest pest models.

While a variety of PBMs have been developed as research tools (Battaglia and Sands 1998), their use by forest managers and analysts has been limited. One factor contributing to this lack of use is the limited accessibility of data needed to drive them. Typically, the units of management—trees and stands—are contained in forest inventory databases. Due to historical and economic factors, these databases contain tree, stand, and site attributes suitable for initializing and driving empirical growth and yield models developed specifically for such databases. PBMs generally have not been built with an inventory processing function in mind, and thus the initialization and driving variables are often unavailable in a forest manager's existing inventory database. Another limiting factor is output suitability. Even if a PBM could be initialized and driven by variables in a forest inventory, the output from PBMs is often not suitable for forest management uses. Updated tree lists and stand/stock tables are commonly needed. However, many PBMs provide only biological variables such as leaf area, carbon biomass, and net primary production. Also, PBMs are not usually built with the ability to simulate the variety of silvicultural prescriptions needed for

[1] Throughout this document, we refer to "Stand-BGC" as well as to "FVS-BGC". "Stand-BGC" refers to the stand-alone version of Stand-BGC. "FVS-BGC" refers to the FVS extension (which was derived from Stand-BGC). As an extension to FVS, FVS-BGC necessarily interacts with the base-model FVS.

forest management analysis and planning. Finally, the time and space resolutions at which PBMs often operate are much higher than that in the empirical growth and yield (G&Y) models currently in use.

Stand-BGC (Milner and Coble 1995) is a PBM that has been designed to allocate simulated stand growth back to individual trees. Operating at this scale allows the results of Stand-BGC to be compared to results from an individual tree growth model such as FVS, although the procedures used to simulate that growth is entirely different. FVS-BGC links the process-based modeling approach from Stand-BGC to FVS' empirical growth approach. This hybrid product provides insights and information available from both approaches, while addressing many of their existing shortcomings.

Extensive eco-physiological research underlies much of the parameterization of the Stand-BGC derived portion of the model, so that potential users of the model are not required to establish values for most of the various process coefficients (although a number of them are user-definable). Furthermore, being linked to FVS, FVS-BGC is initialized from standard forest inventory records. Also, silvicultural treatments—as well as tree regeneration and/or shrub cover establishment—may be simulated within FVS before tree information is passed to FVS-BGC. The linkage of the two models thus provides the user with the benefits of both types of models. At the user's discretion, either the empirical G&Y engine (FVS) may drive tree growth, or the process-driven engine (FVS-BGC) may drive tree growth. In either case, *both* models produce their suite of output files. Simulations may therefore be run in series, one with the FVS-BGC feeding its growth increments to FVS and another without such feedback, and results compared. Although both models remain merely simplifications of reality, similarities or differences between the two runs may lead to ecological insights regarding the stand's future condition, particularly with respect to inferences about climatic effects on stand conditions.

We do not envision that PBMs could—or should—replace empirical models. Empirical G&Y models such as FVS contain a wealth of empirical observation collected over many years and are often well integrated with sophisticated planning systems. Rather, we should strive to enhance these empirical systems by incorporating the useful processes of PBMs where possible. One can imagine a forest analyst processing forest inventory data for a variety of management needs. For an inventory update or a 50-year planning projection, the "empirical" G&Y engine may be used. For an analysis of how stand health or bark beetle risk might vary over the next 20 years with alternative climate scenarios and treatment alternatives, information from the "process" engine may be used. For a 150-year projection of the 1,000 stands in a watershed, the "mixed" option may be used. Projections are made with the empirical engine for the whole period, with a set of process variables to be output every 10 years with the PBM.

This project was inspired by Dr. Albert Stage, USDA Forest Service (retired), Moscow, Idaho who had long advocated such an effort. The project was initiated by the Forest Health Technology Enterprise Team, through the collaboration of authors Smith and Milner. The initial programming to adapt Stand-BGC for use with FVS was developed by Milner with the assistance of Nicholas L. Crookston, USDA Forest Service, Moscow, Idaho. All authors have also been involved in software testing and development. The version documented here is being supported and maintained by the USDA Forest Service Forest

Health Technology Enterprise Team, Fort Collins, Colorado, to keep it current with base code FVS updates. See Appendix E for contact information.

1.2 Using FVS-BGC: An extension of the Forest Vegetation Simulator

This User's Guide describes how to operate the FVS-BGC extension software. The document is consists of three chapters and five appendices. This introductory chapter gives an overview of FVS-BGC and its linkage with FVS. Chapter 2 describes the input information required to run the FVS-BGC extension; it also describes the FVS-BGC's output files. Chapter 3 describes how to run FVS-BGC. The five appendices provide detailed information about the model: (A) a detailed textual "flowchart" of how FVS-BGC works; (B) instructions for running MTCLIM, a pre-processor program that can generate an FVS-BGC-ready climate input file; (C) sample input data files; (D) samples of model output files; and (E) sources of data and model information.

The authors assume that the readers of this guide have a basic understanding of what FVS is and how to use it. The BGC portion of the system involves the simulation of many of the complex processes that are involved in photosynthesis and plant physiology. Explanation of these processes and the detailed description of the BGC portion of the model itself are beyond the scope of this document. As of this writing, we consider this version of the FVS-BGC extension as primarily a vehicle for evaluating the usefulness of this modeling approach. The software has been reviewed and tested for programming errors, and the model logic reviewed and tested for a limited number of test cases.

Like other extensions of FVS, FVS-BGC is "packaged" with FVS as a linked executable. To run the extension, a user should obtain the appropriate FVS executable program. (Source location is provided in Appendix E.) FVS-BGC is invoked from within an FVS simulation via keywords entered by a user into an FVS keyword file. As of this writing, FVS-BGC is not yet packaged as part of the Suppose graphical user interface (with which many users of FVS may be familiar). Therefore, users of the FVS-BGC extension will need to be able to construct keyword sets in a text editor.

The stand conditions simulated by the FVS-BGC extension are initialized by FVS, using either stand input data or FVS-provided default estimates. The following information is passed from FVS to FVS-BGC: the FVS cycle; thinning status; shrub cover information (if the FVS Cover extension is invoked); and the following individual tree record information:

- Species
- Record number
- Diameter at breast height (DBH)
- Height
- Crown ratio (CR)
- Number of trees per acre (TPA) that the record represents ("PROB")

The FVS-BGC extension may operate in one of two "modes": interactive and non-interactive. In the interactive mode, FVS-BGC simulates tree growth and its projected growth increments are passed to FVS, to be used as starting conditions in the next FVS projection cycle. In the non-interactive mode, FVS-BGC runs but its projected growth increments are not used for future FVS growth routines. In either mode, both FVS and FVS-BGC generate output.

If FVS-BGC is being run in the interactive mode, FVS does not grow trees; FVS-BGC does. FVS-BGC passes the following information to FVS when the model is being run in this mode: height growth, diameter growth, crown ratio, and the number of trees per acre that the tree record represents. This information is passed once per cycle, near the end of the cycle. In this mode, FVS serves the following purposes: (1) it provides a method to input entities into BGC (trees via FVS tree lists and the Establishment model; shrubs via the Cover model); (2) it provides a way to simulate silvicultural treatments (thinning and planting); (3) it produces FVS output files reflecting, not only how FVS-BGC "grew" the trees, but also how FVS interprets this growth in terms of the stand's merchantable volume, stand density index (SDI), crown competition factor (CCF), canopy structure, etc.; and (4) it provides a method within which to simulate insect and disease effects on a stand either before or after such a stand is simulated in FVS-BGC.[2] The integration of the two models allows users familiar with FVS output to see how a climate-driven process model projects stand growth. Figure 1 depicts the major FVS and FVS-BGC components and how they are linked. A detailed textual flowchart of the FVS-BGC extension is in Appendix A.

Figure 1 diagrams how the FVS-BGC portion of the model (depicted in shaded region) can operate in either of two modes. After being initialized by the FVS-generated tree list, (and after projecting growth for one FVS cycle), FVS-BGC can either (1) provide its tree growth increments and mortality predictions to FVS (thus overriding FVS's projected increments and mortality); or (2) it can run without inputting its projected increments to FVS. If increments *are* passed from FVS-BGC to FVS (dotted arrow), then FVS-BGC alone grows trees; FVS's growth and mortality projections are ignored. However, any changes to the FVS tree list resulting from FVS-imposed regeneration, planting, or thinning will be made within FVS-BGC at the beginning of the next cycle, when the FVS-BGC entity list gets updated (double-lined arrow).

If increments *are not* passed from FVS-BGC to FVS, then FVS grows trees the same as if FVS-BGC were not run at all. FVS-BGC will be reinitialized by FVS at the beginning of every cycle (using FVS-predicted growth and mortality). Notice that, for case one (when FVS-BGC drives growth), the flow of information is through the two triple-walled boxes. If the model is being run in the non-interactive mode, FVS "grows" the trees, while FVS-BGC simulates and reports daily and annual process dynamics within each FVS cycle. At the beginning of the next FVS cycle, FVS-BGC will be completely reinitialized with entities from FVS. In the non-interactive mode, FVS-BGC still simulates and provides output for within-cycle biogeochemical dynamics. The FVS simulation will be unaffected by FVS-BGC.

[2] Although the current version of FVS-BGC precludes the running of FVS pest extensions in the same run (if FVS-BGC is being operated in the interactive mode), future versions of FVS-BGC could generate vigor indices that could directly interact with insect and disease extensions of FVS.

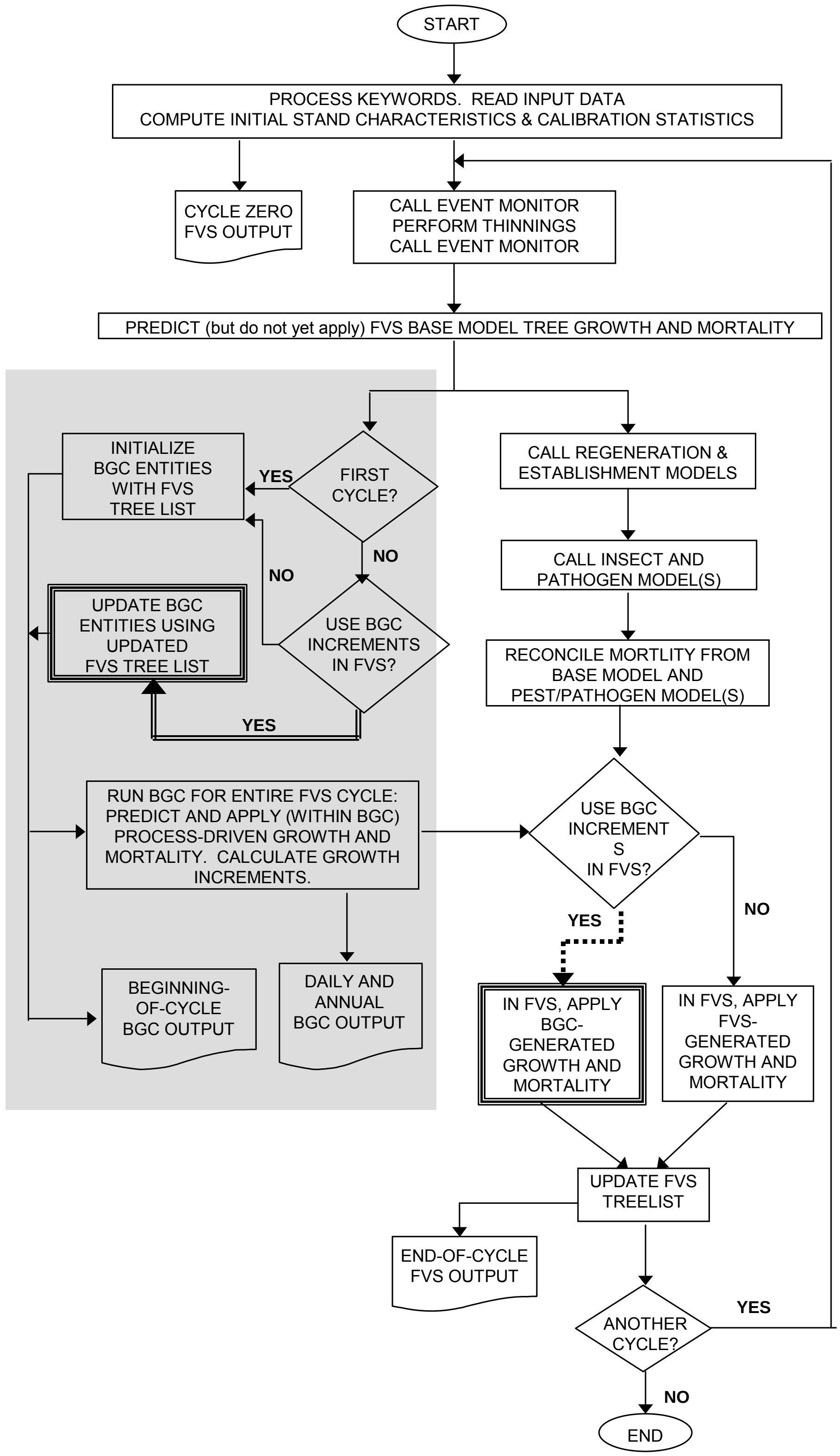

Figure 1. Flowchart illustrating how FVS-BGC interacts with FVS.

2: FVS-BGC INPUT AND OUTPUT

2.1 Input Requirements

The FVS-BGC extension requires three input files: (1) a file containing daily climate data in multiples of 365; (2) a file containing 16 site parameters; and (3) a file containing entity physiological parameters. These three input files are in addition to the keyword and tree data files required by FVS. FVS-BGC recognizes three types (or life-forms) of "entities": trees, shrubs, and grass. Tree entities have a one-to-one correspondence with FVS tree records, and are input through FVS. Shrubs and grasses are represented as indistinct entities, each having a definite height and percentage cover (from which biomass and leaf area will be calculated) on a per area basis. Grass and shrub (collectively: understory) may be input via FVS-BGC keywords. Alternatively, shrub cover information may be input via the FVS Cover extension. The current version of the model has been developed for non-deciduous conifer tree species only; no deciduous tree species are simulated in FVS-BGC. All information passed between FVS-BGC and FVS is done in English units. All other input into FVS-BGC (i.e., the three input files discussed below) must be in metric units (the units on which FVS-BGC operates).

The parameters defined in the site parameter file (SITE.dat) and entity physiology parameter files (BETA.dat) are designed to be user-definable, so that users may (1) calibrate the model to local conditions, (2) change parameterization as more reliable data become available, and (3) examine the consequences of changing underlying assumptions about simulated processes. Without compelling reasons to change these parameters, users should leave most of these parameters at their default values. However, users should appropriately define the site-specific soils-related parameters of the SITE.dat input file (discussed below).

Each of the three input files is described below. Section 3.4 contains a discussion on inputting understory vegetation. Appendix B contains a discussion on a separate pre-processing program—MTCLIM—that may be used to generate an FVS-BGC-ready climate file. Each of the following three input files *must* be named as indicated (CLIMATE.clm, SITE.dat, BETA.dat), and must reside in the same directory on the user's computer as the model executable file.

2.1.1 The Climate File (CLIMATE.clm)

The climate file contains climate data needed to drive the physiological processes of the model. It must: (1) be appropriately formatted, (2) be in the appropriate metric units, and (3) contain multiples of 365 days of weather data, without any missing values. (See Appendix C for appropriate formatting.)

Each line of the climate file represents one day's weather. The seven fields of data required by the model are: Julian day,[3] beginning with day 1 (January 1st); maximum and minimum daily air temperature; relative humidity; incoming solar radiation; precipitation;

[3] Julian days are the days of the year numbered consecutively 1-365. In FVS-BGC, leap year day 366 is ignored.

and atmospheric transmissivity[4] (see Table 1). Since many weather stations only record temperatures and precipitation, users may need to derive relative humidity, radiation, and transmissivity. Furthermore, weather data may be available only from a base station that is many miles away from the forest site under consideration, and at a different elevation, resulting in base-station data that may differ significantly from the site under consideration. These problems are addressed by the program MTCLIM (Hungerford et al. 1989), which is available along with this FVS-BGC extension (see Appendix E).

MTCLIM is a pre-processor that utilizes base station data (daily minimum and maximum temperatures and precipitation) to produce an FVS-BGC-ready climate file containing all seven fields of data. MTCLIM requires a number of initialization parameters characterizing the site and/or the base station, such as slope, aspect, elevation, latitude, mean annual precipitation, temperature lapse rates, etc. Appendix B briefly outlines MTCLIM, including the appropriate formats of its two required input files: the base station weather information, and the site information parameterization file.

Table 1: Sample excerpt from CLIMATE.clm file. (The actual file should be formatted as described in Appendix B, and should not contain headings.)

JULIAN DAY	MAXIMUM AIR TEMP (C)	MINIMUM AIR TEMP (C)	RELATIVE HUMIDITY (%)	RADIATION Kj/m2	PRECIP-ITATION (mm)	TRANS-MISSIVITY
1	-3.05	-22.97	30.56	10319.67	5.30	0.79190
2	-3.05	-14.08	53.92	8942.77	0.00	0.71482
3	1.40	-16.30	36.85	7941.73	0.00	0.65558
4	-1.93	-21.30	32.07	9974.79	0.30	0.77305

2.1.2 The Site Parameterization File (SITE.dat)

FVS-BGC's site parameterization file (SITE.dat) (not to be confused with MTCLIM's site parameterization file) contains 16 parameters, most of which characterize the site's soil(s). Table 2 lists the 16 parameters. No parameter fields may be left blank, and all should contain an explicit decimal point.

The first parameter, S(1), initializes the amount of water in the soil at the beginning of the simulation (January 1st). For a saturated soil, this value would be the maximum volumetric water content, S(3) (m^3/m^3), times 10,000 m^2/ha times soil depth in meters. For a soil at its permanent wilting point,[5] the initial soil water content would be the wilting point volumetric water content times 10,000 times soil depth. Tables 3 and 4 present some estimates of volumetric water content at different water potentials for soils of different

[4] Atmospheric transmissivity is a measure of the clarity of the atmosphere, and is expressed as a decimal fraction (range: 0–1.0; 1.0 = perfectly clear). The transmissivity parameter is used to attenuate the measure of incoming solar radiation.

[5] Water held in the soil at tensions beyond the permanent wilting point is generally unavailable to plants and/or to evaporation. Therefore, soils simulated as being as dry as realistically possible at time zero should still contain some volumetric water, and should not be simulated as having zero volumetric water.

textural classes. These are provided as a guide for users to estimate S(3) and S(1), given soil textural classes. Alternatively, the user may set S(3)[6] to zero, thereby letting FVS-BGC calculate the maximum volumetric water content based on soil texture.

Users should be aware that a soil's water-holding capacities vary depending not only upon soil texture, but also upon other factors, such as organic matter content, bulk density, and amount of coarse fragments (among other things). All of the numbers reported in Tables 3 and 4 assume soils with no coarse fragments (particles larger than 2 mm in diameter). Often, forested sites contain significant amount of coarse fragments within the rooting zone. Since the model does not simulate coarse fragments *per se*, users should reduce the simulated water holding capacity of a stony soil. This should be done via the depth term (parameter S(2), discussed below).[7]

Table 2. Parameters defined in the SITE.dat file.

Example Value	Name	Description
1450.	S(1)	INITIAL SOIL WATER CONTENT (m^3/ha)
1.	S(2)	SOIL DEPTH (m) (effective rooting depth)
0.51	S(3)*	MAXIMUM VOLUMETRIC WATER CONTENT (m^3/m^3). [optional]
500.	S(4)	INITIAL SNOWPACK (as VOLUME OF WATER): (m^3/ha)
0.00065	S(5)	SNOWMELT COEFFICIENT (m °C^{-1} day^{-1})
0.2	S(6)	ALBEDO (Proportion of incoming radiation reflected)
1.	S(7)	CROWN ZONE FLAG (1 = DEPTH; 0 = BY TREE)
1.	S(8)	CROWN ZONE DEPTH (m)
0	S(9)	BARE GROUND (%)
0	S(10)*	Not in use
1.	S(11)	STARTING YEAR (USE 1.)
40.	S(12)	PERCENT SAND
40.	S(13)*	PERCENT SILT (not used)
20.	S(14)	PERCENT CLAY
1.	S(15)	PRECIPITATION MULTIPLIER
0.9	S(16)	PHOTOSYNTHESIS MULTIPLIER

Parameter S(3) is optional. We recommend that users allow FVS-BGC to calculate it (from soil texture) by setting it to zero. Parameters S(10) and S(13) are currently not used. All fields must contain a value. Decimal points should be explicitly entered (for all fields).

[6] We recommend that users allow the model to calculate the maximum volumetric water content (MVWC), rather than explicitly declaring it in the SITE.dat file. If a user declares a MVWC value (in the SITE.dat file) that is inconsistent with the soil's texture, inaccurate estimates of soil water potentials may result, particularly if one enters a MVWC lower than the one listed in Table 3 (for a soil of corresponding texture).

[7] User's should not account for the diminished water-holding capacity of a stony soil via the soil water-holding capacity parameter, S(3). Although this appears to be a logical place for such a correction to be made, doing so will result in erroneous model predictions. The soil water-holding potential equations assume that the soil is stone-free; therefore, reducing S(3) for stones (instead of depth) might result in a simulated soil having unavailable water even if it is saturated.

Table 3. Estimated volumetric water contents (volume of water / volume of soil) of coarse-fragment-free soil of different textures at three different water potentials.

SOIL TEXTURAL CLASS	PERCENT sand	PERCENT silt	PERCENT clay	ESTIMATED VOLUMETRIC WATER CONTENT AT: WP[1]	FC[1]	SAT[2]
SAND (S)	92	4	4	0.04	0.12	0.34
LOAMY SAND (LS)	80	14	6	0.06	0.14	0.37
SANDY LOAM (SL)	65	25	10	0.10	0.23	0.41
LOAM (L)	40	40	20	0.12	0.26	0.47
SILT LOAM (SiL)	15	70	15	0.15	0.30	0.47
SILT (Si)	6	88	6	0.15	0.32	0.43
SANDY CLAY LOAM (SCL)	60	15	25		na	0.47
CLAY LOAM (CL)	34	33	33		na	0.50
SILT CLAY LOAM (SiCL)	10	55	35	0.19	0.34	0.52
SANDY CLAY (SC)	55	5	40		na	0.50
CLAY (C)	20	20	60	0.21	0.36	0.54
SILTY CLAY (SiC)	7	48	45	0.21	0.36	0.54

[1] FC = Field Capacity (-0.01 MPa); WP = Wilting Point (-1.5 MPa). From ASCE (1990).

[2] SAT = Saturated (≈ 0 MPa) (From Saxton et al. 1986). Water content at saturation is the MVWC (referred to in body of text).

Percentages of sand, silt, and clay reported in Table 3 are arbitrary "sample" points representing intermediate values for that textural class. The estimated maximum volumetric water content (MVWC) is the volume of water a soil will hold when it is saturated, divided by the unit volume of soil. The MVWCs in Table 3 ("SAT" column) are derived from an equation from Saxton et al. (1986), which derives MVWC based solely on soil texture. The equation assumes a coarse-fragment-free soil, and is the equation used by FVS-BGC when S(3) is set to zero.

The value of the soil depth term (parameter S(2)), along with textures (S(12-14)) and maximum volumetric water content (S(3)), will have a large influence on the water dynamics in the simulation. Each entity in the simulation has access to only a certain proportion of the site's water. The amount of water available to each entity is a function of the size of the entity's "water bucket." The area dimension of an entity's water bucket is a function of the entity's leaf area. Soil depth defines the depth of each entity's water bucket.[8]

[8] In FVS-BGC, large trees have access to water from the entire soil depth, while small trees (trees < 1.3 m tall), shrubs, and grasses only have access to water from the top half of the soil. Also, since simulated soil depth is reflecting rooting depth, soils that, in reality, are excessively deeper than actual rooting depths (a rarity in most mountainous forest sites, but not unheard of), ought to have their simulated depths reduced to something closer to actual rooting depths.

Soil rooting depths are routinely reported in soil surveys, along with soil textures and stoniness (amount of coarse fragments). As mentioned above, depth should be corrected for stoniness. A simple, if crude, method for such an adjustment is to *reduce the effective rooting depth of the soil by the relative proportion of stoniness* (since coarse fragments have negligible water holding capacity). Although soil surveys typically do not report *percentages* of coarse fragments, the use of adjectives describing how many coarse fragments are present follows specific rules (Table 5). Users may thus reduce the effective depth of the simulated soil by some amount corresponding to the amount of coarse fragments denoted by the description in the soil survey, prorated by the proportional depth of the horizon for which the descriptor is used (see Table 5).

Parameter S(4) represents the amount of *water* in the initial snow pack in m^3/ha. This is used only upon initialization (day 1, year 1, cycle 1) to put snow on the ground. Thereafter, the weather data stream determines snow loading. One inch of water over one hectare equals 254 m^3/ha. The snowmelt coefficient (S(5)) determines how fast the snow pack water enters the soil water pool. Albedo (S(6)) determines how much of the incoming solar radiation will be reflected from the site, and thus unavailable for photosynthesis.

Table 5. Guide to interpreting coarse fragment modifiers in soil survey texture descriptions.

COARSE FRAGMENT DESCRIPTOR (occurring before soil texture descriptor: [e.g., very gravelly sandy loam])	Amount of coarse fragments present (if this descriptor is used)	Suggested proportional decrease in simulated soil depth in FVS-BGC
No coarse fragment modifier	< 15%	None
Gravelly, cobbly, or stony	15-35%	25%
Very gravelly, cobbly, or stony	35-60%	47.5%
Extremely gravelly cobbly, or stony	> 60%	75%

Note that each soil horizon described in a soil survey will have its own texture and coarse fragment modifier. Soil depths used in FVS-BGC that are determined from soil survey-reported horizon depths should be reduced by the proportion of coarse fragments in each horizon to yield the effective rooting depth (to be used as parameter S(2). That is, [percent reduction • horizon thickness] summed across all described horizons = effective soil depth (equivalent stone-free soil depth).

Parameters S(7) and S(8) allow the user to choose how the canopy zones are divided in the simulation. Each entity has a crown of some definite size and shape (cones for trees; cylinders for shrubs and grasses). Collectively, the entities' crowns comprise the site's canopy. Incoming radiation is simulated such that the canopy absorbs radiation stratum by stratum, from the top down, attenuating it by the amount absorbed by the layer(s) above. Parameter S(7) controls how the canopy strata will be defined. If using the "depth method," the canopy will be divided into zones of equal depth (thickness); the depth of zones is then defined by parameter S(8). Alternatively, the user may specify that canopy zones be defined by the entities themselves. By setting S(7) to zero, the user invokes the "entity method," whereby the tops and bottoms of all entity crowns define the canopy zones (and in which case S(8) will be ignored). Thus, for ***n*** simulated entities, there will be (at most) 2***n***-1 canopy zones, each having variable thickness. Whichever method is used, the zones are recalculated annually (thereby accounting for annual changes in crown structures).

Percent bare ground (parameter S(9)) is used in the model to simulate areas that cannot be occupied by an entity's roots. This term only affects the size of each entity's water bucket. Its affect is proportionally the same across all entities. It should not be used to adjust for areas of bare ground that in the future could be occupied by an entity's roots; rather, it should be used to represent areas where entities cannot ever root (e.g. rock outcrops, bodies of water, etc.)

Parameter S(10) is currently not used. Parameter S(11) should be set to one, and (like all values herein) should be entered with a decimal point.

The soil texture parameters (S(12) and S(14)) are used in two functions in the model. First, if S(3) (the maximum volumetric water content) is set to zero, then S(3) will be calculated from soil texture. Secondly, soil textures are used to determine daily soil water potentials (which in turn are used to determine daily leaf water potentials). Parameter S(13) (percent silt) is currently not used. If specific percentages of sand and clay are not available, the "representative" textures for each textural class reported in Table 3 may be used[9]. Soil textures reported in a soil survey will, like stoniness, vary by depth, and therefore, like stoniness, should be prorated by depth, so that the single values entered for S(12-14) represent the "average" conditions throughout the rooting depth.

Parameters S(15) and S(16) allow the user to directly increase or reduce precipitation (S(15)) or gross photosynthesis (S(16)). For example, if the precipitation multiplier (S(16)) is set to 1.1, every input of precipitation into FVS-BGC will be 10 percent greater than the amount originally read in from the CLIMATE.clm file. Likewise, if the photosynthesis multiplier (S(16)) is set to 0.9, the gross photosynthesis (total carbon fixed by an entity before respiration) from each canopy layer from each entity will be reduced by 10 percent. These parameters are useful for sensitivity testing. They also provide a means to calibrate the model in a crude way.

2.1.3 The Entity Parameterization File (BETA.dat)

The entity-level parameterization file contains 13 life-form-specific parameters and 22 life-form-independent parameters (Table 6). As with the SITE.dat file, no parameter fields may be left blank, and all should contain an explicit decimal point. These parameters were adapted from Forest-BGC (Running and Coughlan 1988, Running and Gower 1991). Elaboration of these parameters is beyond the scope of this guide. Units and brief definitions of the parameters are reported in Table 6. Values reported are provided as defaults, and are based on a variety of sources. Additionally, a chart indicating which simulated process uses which parameters is presented in Table 7. All of these parameters are referred to in the more detailed description of the model in Appendix A. A description of the appropriate formatting for this input file is given in Appendix C.

- Because the current version of the model does not distinguish between coarse and fine roots, parameters regarding coarse roots—B1(6), B2(9), B2(13), and B2(21)—are not used.
- Parameters B1(12) and B2(22) also are not used.
- Parameters B2(11, 12, and 14) are only used at the end of the first year, are not used for grasses, and should sum to one. After year one, FVS-BGC recalculates allocation fractions; see Appendix A for details on this process.

[9] Each soil textural class encompasses a range of percentages of sand, silt and clay. The values reported in Table 3 are arbitrary "midpoints" for each textural class.

Table 6. Description of parameters of the BETA.dat file. The first 13 parameters are life-form-specific (i.e., can be defined separately for trees, shrubs, and grasses).

Life Form (LF) Dependent:				
Trees	**Shrubs**	**Grasses**	**Name**	**Parameter Definition**
0.0016	0.0016	0.006	B1(1,LF)	MAXIMUM LEAF CONDUCTANCE (g_s) (m/s)
0.5	0.5	0.5	B1(2,LF)	MAXIMUM (least negative) LWP (-MPa)
0.1	0.1	0.01	B1(3,LF)	BOUNDARY LAYER CONDUCTANCE (m/s)
0.0002	0.0004	0.0044	B1(4,LF)	MAINTENANCE RESPIRATION C LOSS RATE IN LEAVES at 0 °C (kg/day)
0.0002	0.0002	0 (na)	B1(5,LF)	MAINTENANCE RESPIRATION C LOSS RATE IN STEM at 0 °C (kg/day)
~~0.0002~~	~~0.0002~~	~~0.0003~~	~~B1(6,LF)~~	~~COARSE ROOT RESPIRATION~~ (not used)
0.0004	0.0011	0.0044	B1(7,LF)	MAINTENANCE RESPIRATION C LOSS RATE IN ROOTS at 0 °C (kg/day)
4	4	6	B1(8,LF)	MAXIMUM PHOTOSYNTHESIS RATE (µmol m^{-2} s^{-1})
33	50	50	B1(9,LF)	LEAF TURNOVER (SENESCENCE) (%/yr) (after growth)
0	20	0 (na)	B1(10,LF)	STEM TURNOVER (SENESCENCE) (%/yr) (after growth)
40	80	50	B1(11,LF)	ROOT TURNOVER (SENESCENCE) (%/yr) (after growth)
~~33~~	~~18~~	~~17~~	~~B1(12,LF)~~	~~LEAF LIGNIN CONCENTRATION (%)~~ (not used)
25	35	25	B1(13,LF)	SPECIFIC LEAF AREA (m^2/kg) (all-sided)
Life-Form Independent				
	0.0005		B2(1)	RAIN INTERCEPTION COEFFICIENT (m lai^{-1} day^{-1})
	-0.5		B2(2)	CANOPY LIGHT EXTINCTION COEFFICIENT (lai^{-1})
	1.65		B2(3)	LWP AT STOMATAL CLOSURE (-MPa)
	25		B2(4)	VPD AT STOMATAL CLOSURE (mbar)
	20		B2(5)	OPTIMUM TEMPERATURE for PHOTOSYNTHESIS (°C)
	45		B2(6)	MAXIMUM TEMPERATURE for PHOTOSYNTHESIS (°C)
	0.35		B2(7)	GROWTH RESPIRATION C LOSS RATE IN LEAVES (fraction/yr)
	0.3		B2(8)	GROWTH RESPIRATION C LOSS RATE IN STEMS (fraction/yr)
-	~~0.3~~	-	~~B2(9)~~	~~COARSE ROOT GROWTH RESPIRATION. FRACTION~~ (see Appendix F)
	0.35		B2(10)	GROWTH RESPIRATION C LOSS RATE IN ROOTS (fraction/yr)
	0.15*		B2(11)	FRACTION of CARBON ALLOCATED TO LEAVES in first year (fraction/yr)
	0.35*		B2(12)	FRACTION of CARBON ALLOCATED TO STEM in first year (fraction/yr)
-	~~0.05~~	-	~~B2(13)~~	~~COARSE ROOT CARBON ALLOCATION FRACTION~~ (see Appendix F)
	0.5*		B2(14)	FRACTION of CARBON ALLOCATED TO ROOTS in first year (fraction/yr)
	2.3		B2(15)	RATIO ALL-SIDED LAI TO 1-SIDED LAI
	0.01		B2(16)	SLOPE OF g_s vs PAR ((mm s^{-1}) / (µE m^{-2} s^{-1}))
	0.069		B2(17)	COEFFICIENT FOR MAINTENANCE RESPIRATION (1/s) (Q_{10}=2.0)
	0.5		B2(18)	MASS FRACTION OF C IN DRY MATTER (dimensionless)
	0.66		B2(19)	MAX RATIO OF NEW LEAF C / NEW (LEAF + ROOT) C (dimensionless)
	0.19		B2(20)	WATER STRESS INTEGRAL FRACTION
-	~~0.85~~	-	~~B2(21)~~	~~STEM/COARSE ROOT ALLOCATION RATIO~~ (See Appendix F)
	0.25		B2(22)	FRACTION OF TOTAL STEM CARBON IN BRANCHES

Abbreviations:

- LF = life form
- g_s = stomatal conductance
- LAI = Leaf Area Index
- LWP = Leaf Water Potential
- VDP = Vapor Pressure Deficit
- C = carbon
- PAR = Photosynthetically Active Radiation; na=not applicable;
- Q_{10} = respiration quotient: (change in rate of respiration for 10 °C change in temperature)

* The values reported for B2(11,12,14) are used for trees and shrubs (and should sum to one). For grasses, the first year allocation fractions are hard-coded at 50 percent for both roots and leaves (grass has no simulated stem). They are used at the end of the first year only; thereafter they are recalculated annually, entity-by-entity.

Table 7. Chart indicating which parameters (defined in Table 6) are used in various subroutines of FVS-BGC.

PARAMETER	PARAMETER USED IN ROUTINE THAT CALCULATES:					YEAR END BIOMASS	NEXT YEAR'S ALLOCATION
	ABS RAD	STOM COND	TRANSP	PSN	MAINT RESP		
B1(1,LF)		X					
B1(2,LF)		X		X			
B1(3,LF)			X				
B1(4,LF)					X		
B1(5,LF)					X		
B1(6,LF)	CURRENTLY NOT USED						
B1(7,LF)					X		
B1(8,LF)				X			
B1(9,LF)						X	
B1(10,LF)						X	
B1(11,LF)						X	
B1(12,LF)	CURRENTLY NOT USED						
B1(13,LF)	USED TO CALCULATE ALL-SIDED LEAF AREAS FROM LEAF BIOMASS						
B2(1)	USED TO REDUCE INCOMING PRECIPITATION (PPT_{SOIL}=PPT - (LAI •B2(2))						
B2(2)	X	X		X			
B2(3)		X		X			X
B2(4)		X					
B2(5)		X		X			
B2(6)		X		X			
B2(7)						X	X
B2(8)						X	X
B2(9)	SEE APPENDIX F						
B2(10)						X	X
B2(11)						X	X
B2(12)						X	X
B2(13)	SEE APPENDIX F						
B2(14)						X	X
B2(15)	X	X		X			
B2(16)		X					
B2(17)					X		
B2(18)	USED TO CONVERT BIOMASS TO C (AND VICE VERSA)						
B2(19)							X
B2(20)							X
B2(21)	SEE APPENDIX F						
B2(22)	USED FOR INITIALIZING SMALL TREE C POOLS						

Abbreviations:

- ABS RAD = routine that calculates amount of incoming radiation absorbed by canopy
- STOM COND = routine that calculates stomatal conductance
- TRANSP = transpiration subroutine (loss of water from soil)
- PSN = photosynthesis subroutine (carbon fixation)
- MAINT RESP = maintenance respiration subroutine (carbon loss)
- LF = Life form
- PPT_{SOIL} = precipitation infiltrating into the soil
- PPT = precipitation
- LAI = Leaf Area Index
- C = carbon

"Next year's allocation" refers to the routine that recalculates how C will be allocated among each entity's leaf, stem, and root pools the following year. See Appendix A for more detail.

2.2 FVS-BGC Model Output

FVS-BGC produces five output files: two reporting stand-level processes and attributes, and three reporting entity-level processes/attributes. Example output file excerpts are provided in Appendix D. The five files, described in detail in the following section, are:

YRSTAND.OUT	Stand-level carbon and water balance by year
DAYSTAND.OUT	Stand-level carbon and water balance by day
YRENTY.OUT	Entity-level summary of annual carbon dynamics: amounts of radiation absorbed, amounts of carbon fixed and respired, and tissue pool carbon balances at end of the year
ENTYLST.OUT	Summary of end-of-year entity attributes: dimensions and growth increments
DEAD.OUT	End-of-year summary of entities that have died

YRSTAND.OUT

End-of-year site carbon and water balances for each year of the simulation.

FVS CYC	The current FVS cycle.
YEAR	The year within FVS cycle. Year zero is the beginning of the first year, prior to any growth.
YRPSN	Gross canopy photosynthesis. The amount of carbon fixed by all of the leaf area in the stand (trees plus understory vegetation) before accounting for maintenance or growth respiration (kg/ha).
YRTRANS	The total amount of water transpired for all leaf area in the stand during the year (m^3/ha).
YRMRESP	The total amount of carbon lost via maintenance respiration for all plants during the year (kg/ha). This loss is subtracted from gross canopy photosynthesis to determine the amount available for plant growth.
YRGRESP	The total amount of carbon lost via growth respiration for all plants during the year (kg/ha). This loss is subtracted from the carbon allocated to plant parts prior to updating plant dimensions.
LAI_GR	All-sided leaf area index of grass species at the end of the year (m^2/m^2).
LAI_SH	All-sided leaf area index of shrubs at the end of the year (m^2/m^2).
LAI_SM	All-sided leaf area index of small trees (< 4.5 feet [1.77 m] in height) at the end of the year (m^2/m^2).
LAI_LG	All-sided leaf area index of large trees (≥ 4.5 feet [1.77 m] in height) at the end of the year (m^2/m^2).
SITELAI	Total leaf area index (all sided) of all vegetation (trees, shrubs, grasses, forbs) on the site at the end of the year (m^2/m^2).
TSTEM	Total carbon in live trees, including stems, roots and branches, at the end of the year (kg/ha).
CCF	Crown competition factor at the end of the year.

ABSRAD Total solar radiation absorbed by all vegetation in the stand during the year (GJ/ha).

DAYSTAND.OUT

Site carbon and water balances on a Julian day basis for each year of the simulation. This file is useful for examining daily climate inputs and their effects on the onset of water stress, photosynthesis, and respiration.

FVS CYC The current FVS cycle.

YEAR Year within the FVS cycle. (Year zero is not reported.)

JD Julian day.

PPT Precipitation for the given day (mm).

TMAX Maximum 24-hour temperature (°C)

TMIN Minimum 24-hour temperature (°C)

PSN Gross canopy photosynthesis for the day (kg/ha) before maintenance or growth respiration.

TRANS Amount of water transpired by all vegetation for the day (m^3/ha).

MRESP Maintenance respiration of all vegetation for the day (kg/ha).

SWP1 Soil water potential in the top half of the soil profile (-MPa).

SWP2 Soil water potential in the bottom half of the soil profile (-MPa).

RADTOP Radiation incident at the top of the canopy for the day (kJ/m^2).

RADBOT Radiation incident at the ground for the day (kJ/m^2).

SITELAI Total LAI (all-sided) on site (m^2/m^2).

YRENTY.OUT

This file allows a user to see how carbon is fixed and allocated to each entity's leaf, stem, and root pools on an annual basis for every year of the simulation.

FVS CYC The current FVS cycle.

YEAR Year within the FVS cycle. Year zero is prior to any growth.

ETY An internal numbering of the entities alive at the start of the simulation year.

TREE The unique permanent tree number (corresponding to the FVS tree number).

SP Two-letter species code from FVS treelist [for trees]. For user-supplied understory, this is the two-letter code provided in the supplemental record (see Section 3.3).

PSN Entity gross photosynthesis. Amount of carbon fixed by each entity for the year, before maintenance and growth respiration. (kg).

TRANSP Amount of water transpired by the entity for the year (m^3).

MRESP Amount of carbon used for the year for maintenance respiration for the entity (kg).

GRESP Amount of carbon used for the year for growth respiration for the entity (kg).

LEAF Amount of carbon in live entity foliage at the end of the year, after turnover (kg).

STEM Amount of carbon in stems (including bole and branches) of live plants at the end of the year, after turnover (kg).

ROOTS Amount of carbon in roots of live entities at the end of the year after turnover (kg).

ABSRAD Amount of radiation absorbed by each entity for the year (GJ).

TURNOVR Amount of carbon lost by each entity from senescence (sum from all tissue pools) (kg).

ENTYLST.OUT

Reports a list of entities and their beginning-of-year dimensions and annual growth increments. The table is produced for each year of each FVS cycle. Note that this table uses English measurements.

FVS CYC The current FVS cycle.

YEAR Year within the FVS cycle.

INDX An internal numbering of the entities alive at the start of the simulation year. (Same as column ETY in YRENTY.OUT).

ID A life form identifier: T = tree. G = grass. S = shrub.

TRENO The unique permanent tree number (corresponding to the FVS tree number).

IHT Initial height of trees for the current year (ft.).

IDBH Initial DBH (outside bark) of trees for the current year (in.).

ICR Initial crown ratio for trees (decimal fraction).

ICW Initial crown width for trees (ft.).

ICOV Initial percent cover (reported for understory entities only).

HG Height growth for the year (ft.).

DG Diameter growth (inside bark) for the year (in.).

CRINC Difference of end-of-year CR and beginning-of-year CR (percent).[10]

CUMHG Cumulative height growth during the cycle (ft.).

CUMDG Cumulative DBH growth during the cycle (in.).

[10] Initial crown ratios (CR) reported in column ICR are in decimal fractions. The CRINC is the (end-of-year CR – beginning-of-year CR) • 100. It is not the percent change in crown ratio (new CR - old CR / new CR): it is the net change in CR as a percent of tree height.

COVINC Difference in percent cover for each understory entity (end-of-year percent cover – beginning-of-year percent cover) (percent).

SP Two-letter species code from FVS treelist [for trees]. For user-supplied understory, this is the two-letter code provided in the supplemental record (see Section 3.3).

DEAD.OUT

Reports mortality projections from FVS-BGC. The user can see when an entity was considered dead during a cycle and examine its attributes at the time of death.

FVS CYC The current FVS cycle.

YR Year within the FVS cycle in which the entity died.

ID The type of entity: T=tree, S=shrub, G=grass

TREE The unique permanent tree number (corresponding to the FVS tree number).

SPP Two-letter species code from FVS treelist [for trees]. For user-supplied understory, this is the two-letter code provided in the supplemental record (see Section 3.3).

BD Basal diameter (at ground level) of tree entity (cm, outside bark).

DBH Diameter at breast height (outside bark) of the entity (if a tree) (cm).

HT For trees: Total height of entity (m). For shrubs and grass: Average canopy height (m).

CR Crown ratio (decimal fraction; reported for trees only).

TPH Trees per hectare that the tree record represents (reported for trees only).

BA Basal area (outside bark) of the entity (m^2) (reported for trees only).

CCF Contribution to CCF (for trees only).

LA Leaf area (all-sided) of the entity (m^2).

LEAF Leaf carbon for the entity (kg C).

STEM Stem carbon (including branches) of entity (kg C).

ROOT Root carbon of entity (kg C).

3: RUNNING FVS-BGC

As stated in Chapter 1, FVS-BGC can be run in one of two modes. At the user's option, either FVS-BGC will supply its projected tree growth increments and tree mortality to FVS (thus over-riding FVS's growth and mortality projections), or standard FVS growth and mortality projections will be used. In either scenario, both FVS and BGC will produce their suites of output files, reflecting how the trees/entities were grown within the cycle. This chapter describes the FVS-BGC keywords. An example keyword set follows at the end of this chapter.

3.1 "Turning-on" FVS-BGC

The FVS-BGC extension is invoked via keyword **BGCIN**. This keyword activates the extension, and informs the FVS program that the following keywords are FVS-BGC keywords. Keyword BGCIN *must* be used, and used first, if any other FVS-BGC keywords are to be used. An **END** keyword is subsequently required, indicating the end of FVS-BGC keywords. BGCIN activates the running of the FVS-BGC extension. If BGCIN is used *without* keyword **BGCGROW** (see below), then FVS-BGC will run, and its entity list will be completely reinitialized by FVS at the beginning of each FVS cycle. FVS-BGC increments will *not* be used by FVS to determine initial conditions for the next growth cycle, and *FVS will run as if FVS-BGC were not running at all*. The output that FVS-BGC will produce will reflect its *within-cycle* predictions of growth, mortality, and carbon and water balances. If this keyword is used, then the three required input files must reside in the same directory as the one in which the model executable resides. Keyword BGCIN has no associated parameter fields.

3.2 Invoking the Use of FVS-BGC's Projected Increments in FVS

Keyword **BGCGROW** informs the FVS program that, in FVS, FVS-BGC's projections of tree growth and mortality are to be used in place of FVS's projections for the starting conditions for the next cycle in place of FVS's projections. The following information is passed from FVS-BGC to FVS: height growth, diameter growth, crown ratio, and the density (trees per acre) that the tree record represents. (Data regarding understory are not passed from FVS-BGC to FVS.) Note that, in FVS-BGC, a single tree ***record*** is "grown" as a single entity. The density that each record represents in FVS-BGC will always be either the same as when it was initialized (at the beginning of the cycle) or zero. In other words, unlike in FVS (where the trees per acre represented by each tree record may change over time as mortality is introduced), an entity in FVS-BGC—while still representing some density of trees—is simulated as a single entity. For example, if tree record *1001* represented 20 TPA (in both FVS and BGC), mortality may be imposed in FVS such that, at some future date, record A might represent 18.5 TPA. In FVS-BGC, however, record A will always represent 20 TPA (throughout the FVS cycle in which it was set to 20), unless conditions are sufficiently stressful enough to "kill" the record, in which case the record will represent zero TPA.

If this keyword is used, the FVS treelist will be updated by using FVS-BGC's projections of growth and mortality at the end of the FVS cycle. At the beginning of the next cycle, FVS only updates FVS-BGC's entity list if there were any management actions (e.g., thinnings and/or plantings) introduced at the beginning of the current cycle, or tree re-establishment during the previous cycle. Keyword BGCGROW has no parameter fields.

Note that if FVS-BGC-projected growth and mortality is being used in FVS, then all growth and natural mortality projections arising from the non-BGC portions of FVS will be overridden, including predictions arising from insect and pathogen extensions. The current version of FVS-BGC precludes the functional operation of such extensions simultaneously.

3.3 Entering Understory Vegetation

Because FVS-BGC is a process-based, climate-driven model, tree growth is sensitive to the amount of understory vegetation. For FVS-BGC to accurately project tree growth and mortality, it is important to accurately portray the entire complement of vegetation on a site—not only trees, but understory vegetation as well.

Understory vegetation information may be provided to FVS-BGC in one of two ways. Both methods may *not* be used together. ***Shrub*** understory vegetation may be input either (1) via the Cover extension to FVS (Moeur 1985), or (2) via supplemental records in the keyword file (using FVS-BGC keyword **UNDERVEG**—see below). ***Grass*** understory vegetation may *only* be input via supplemental records following the UNDERVEG keyword.

Keyword **VEGOPT** informs the program which method will be used to input understory vegetation. This keyword has one required parameter field (in columns 11-20).

Field 1 — 1 = understory vegetation will be entered via the Cover extension.

2 = understory vegetation will be entered via FVS-BGC keyword UNDERVEG (see below).

Keyword **UNDERVEG** signals that understory vegetation information will follow in a set of supplemental records. The keyword **ENDENT** at the end of the list of supplemental records signals the end of the understory vegetation entity input data. Keyword **UNDERVEG** has no parameter fields.

Each supplemental record contains four fields/attributes. Unlike other FVS supplemental record fields (which are column-delimited), **UNDERVEG** supplemental record fields are *space delimited*. Each vegetation entity entered may represent a single species, or may represent a suite of species. The user may specify as many entities as necessary to describe the understory community. Note, however, that while separate understory vegetation entities may differ in terms of their height or percent cover, each understory vegetation entry must be classified as either a grass or a shrub. It is this life form designation that will dictate which of the life form-specific physiological parameters and functions will be used during the simulation.

All understory vegetation input as a shrub will be grown using one set of shrub growth functions and parameters, and all understory vegetation entered as a grass will be grown using a single, grass-specific set of functions and parameters. There are no simulated species-level differences. Any differences seen in model output among identical life forms will be a result of differences in the initial height or percent cover.

The four fields of the supplemental record(s) are:

Field 1: — Life form. G=grass; S=shrub. The life form code is used to access the appropriate biomass equations and physiological parameters in FVS-BGC.

Field 2: Species. This user-defined two-letter designation is only used as a label in model output, and does not affect the simulation.

Field 3: Height in feet. Average entity height (throughout the simulated stand) of the life form entity at the beginning of the simulation. (Real number. A decimal point and digits to one or more decimal places are optional.) Grasses do not grow in height. Shrubs are constrained to grow no higher than 2 meters.

Field 4: Percent cover. Average percent cover (throughout the simulated stand) of the life form entity, at the beginning of the simulation. (Real number. A decimal point and digits to one or more decimal places are optional.)

Keyword **ENDENT** signals the end of vegetation supplemental records. This keyword must be used if keyword UNDERVEG is used.

Keyword **END** signals the end of FVS-BGC keywords. This keyword must be used if BGCIN is used.

SUMMARY OF FVS-BGC KEYWORDS	
BGCIN	Invokes the FVS-BGC portion of the model.
BGCGROW	Signals that FVS-BGC growth increments and mortality are to be used in FVS in place of FVS's projections.
VEGOPT	Flag indicating how understory vegetation is to be entered. 1 = use Cover model; 2 = read supplemental records.
UNDERVEG	Signals understory supplemental records will follow.
ENDENT	Signals end of understory supplemental records.
END	Signals end of FVS-BGC keywords.

3.4 Miscellaneous Notes and Special Considerations

3.4.1 Tree Species Recognition

FVS-BGC currently recognizes only coniferous tree species. The model was developed using the North Idaho (NI) variant of FVS, consequently the model recognizes all NI variant conifer species plus whitebark pine. The model also recognizes eleven additional conifer species from eight western FVS variants, insofar as these additional 11 species have been "redefined" within FVS-BGC (see Table 8) so that the algorithms that perform operations at the species-level (see below) recognize them as one of the 11 conifers to which the model is calibrated.

A number of the functions in FVS-BGC pertaining to tree geometry are species-specific. For calculations of bole volume (which is a function of DBH and height), and initializations of biomass to the various tissue pools (leaf, stem, root), species-specific parameters exist for Douglas-fir (DF), lodgepole pine (LP), ponderosa pine (PP), and western larch (WL). The DF parameters are the defaults for all other tree species.

Crown competition factor (CCF) and crown width (CW) functions in FVS-BGC have been calibrated for the ten NI variant conifers, plus whitebark pine (see Table 8). Crown geometries, therefore, are species-specific. There is no default. Table 8 indicates how FVS-BGC treats the additional eleven (for a total of 22) conifer species (from the western variants mentioned above) in the CCF and CW functions. Since only these 22 conifers have been defined, only these tree species currently may be simulated in FVS-BGC. Users can re-label other species as any of the 22, so that crown geometry functions are available.

In FVS-BGC, simulated rates of photosynthesis, respiration, and transpiration are **not** species specific. Different rates of these processes by different entities (of the same life form) will be determined solely on entity geometry and relative allometric relationships. How the annual fixed carbon is distributed in terms of height and diameter, however, is species dependent, with DF, LP, PP, and WL each having their own ratios of stem carbon[11] to bole volume, as well as their own bole volume-to-height and bole volume-to-DBH equations. Again, DF is the default for all other species. See the detailed description in Appendix A for more information regarding entity-level carbon allocation.

3.4.2 Tripling of Tree Records

If FVS-BGC-projected growth increments are used to project FVS growth (that is, if keyword BGCGROW is invoked), then "tripling"[12] in FVS must be turned off. Stand BGC is currently not equipped to handle the updated treelist from FVS if tripling has occurred. (Tripling *is* permitted if FVS-BGC is being run in the non-interactive mode, because in that case FVS-BGC's entity list gets completely reinitialized by FVS at the beginning of each cycle.) Therefore, in simulations invoking the interactive mode of FVS-BGC, ***the FVS keyword NOTRIPLE must be used***.

3.4.3 Tree Regeneration and Establishment

The Regeneration and Establishment Model (Ferguson and Crookston 1991) automatically schedules natural regeneration in the following FVS geographic variants: Central Idaho, Eastern Montana, Kootenai/Kaniksu/Tally, and North Idaho (of those variants mentioned in Table 8). If a user does not want natural regeneration scheduled, keyword NOAUTOES ought to be used. If regeneration is scheduled, new trees will be added periodically to the FVS treelist, and therefore, subsequently will be added to FVS-BGC's entity list at the beginning of the next cycle.

[11] In FVS-BGC, stem carbon = (bole + branch + twig + bark) carbon. The user initializes allocation of carbon to each entity's leaf, stem, and root pools via parameters in BETA.dat. In all years other than year one, FVS-BGC recalculates these allocation ratios on an entity-by-entity basis based on water stress (among other things). These new allocation ratios are *not* species dependent (but *are* life form-specific).

[12] Tripling is a feature in FVS whereby tree records are split into three, with each new record representing a fraction of the density that the un-tripled record represented. This allows for more simulated variation in individual tree record-level growth and mortality responses due to the various random growth and mortality effects built into FVS.

Table 8. Conifer tree species currently recognized by FVS-BGC.

Conifer Species for which CW and CCF Calculations Exist in FVS-BGC	Other Conifer Species Recognized in FVS-BGC and Treated (for CW and CCF calculations only) as the Species in Column One
Subalpine fir	
Douglas-fir	
Engelmann spruce	Blue spruce; white spruce
Grand fir	Corkbark fir; white fir; silver fir
Lodgepole pine	
Ponderosa pine	
Western redcedar	
Whitebark pine	Bristlecone pine; limber pine; pinyon pine; western juniper
Western hemlock	Mountain hemlock
Western larch	
Western white pine	Southwestern white pine

The second column includes all conifers (besides those listed in column one) from the following western FVS variants: Blue Mountains, Central Idaho, Central Rockies (GENGYM), Eastside Cascades, Eastern Montana, Kootenai/Kaniksu/Tally Lake-Flathead (KOOKANTL), Tetons, and Utah. Column one includes all conifer species from the North Idaho (Inland Empire) variant, plus whitebark pine.

3.5 Example Keyword Set

Line numbers in the example below are provided for illustrative purposes only. They would not be part of the keyword file itself.

```
1  COMMENT
2  Example keyword file.  Runs one stand for five cycles (line 8).
3  (Default cycle length will be 10 years).  FVS-BGC is "turned on" (line 30).
4  FVS-BGC will supply growth increments to FVS at the end of each cycle (line 31).
5  Understory vegetation is entered via FVS-BGC keywords (lines 33, 38-43).
6  END
7
8  NumCycle          5
9
10 StdIdent
11 00000005
12 InvYear        1994
13 ModType           5
14 StdInfo         215         5        99        90        50        87        41
15 Design            0         1       999         5              103.78         1
16 SiteCode                   71
17
18 TREEDATA
19    1001 92.591LP  8.9 .6 61  0  .03 0 074 0 0 021
20    1002 65.271LP 10.6 .2 68  0  .02 0 0 0 0 0 011
21 ...more records would be here...
22    9007 48.481LP 12.3 .0 59  0  .05 0 0 0 0 0 011
23 -999
24
25 NOTRIPLE
26 NOAUTOES
27
28 *****  BGC KEYWORDS  *****
29
30 BGCIN
31 BGCGROW
32 *
33 VEGOPT            2
34 *
35 **20% cover of 1' tall grass/forb
36 **10% cover of 2' tall shrub
37 *
38 UNDERVEG
39 G GR 1 20
40 S SH 2 10
41 ENDENT
42 *
43 END
44 *****  END OF BGC KEYWORDS  *****
45
46 PROCESS
47 STOP
```

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On-line resources:

Information and related to the Forest Health Technology Enterprise Team FVS-BGC related downloads will be available at this site:

http://www.fs.fed.us/foresthealth/technology/products.htm

Information and publications related to the BGC family of models Numerical Terradynamic Simulation Group, University of Montana:

http://www.forestry.umt.edu/ntsg/

Information and publications related to FVS system and extensions Growth and Yield Unit of the Forest Management Service Center:

http://www.fs.fed.us/fmsc/fvs/index.php

APPENDIX A: TEXTUAL FLOWCHART OF FVS-BGC

(A list of abbreviations and acronyms follows the text.)

This section describes the sequence in which the model performs the major operations of the simulation, and provides a small amount of detail regarding the operations themselves.

1) Load entity information from FVS to BGC:

- FVS cycle information
- Thinned status
- Tree record number (from inventory) and index (its ranking in a numerically-ordered list of record numbers)
- Tree record attributes: Species, PROB, DBH, HT, CR
- Percent cover and height of grasses and shrubs (from FVS Cover model, if applicable)

2) At beginning of year:

- Calculate bole volume based on DBH (two methods: one for large trees, one for small trees)

  Small tree (< 2" DBH): species independent, assume parabolic bole shape

  Large trees, volume is species-dependent (for DF, PP, LP, and WL. All other species use DF)
- Convert bole volume to biomass (assume constant 500 kg / m^3)
- Convert bole biomass to mass of C (assume constant 50 percent for all tissues)
- Calculate total biomass (and mass of C) of other entity pools (bark, root, branch, leaf) based on bole C.

  For small trees (< 2" DBH): stem C = 1.25 • bole C (where stem C = bole + branch + bark + twig)

    For small trees < 4.5' tall: leaf C ≈ 1.29 • stem C

    For small trees ≥4.5' tall: leaf C = f (HT, CR, TPH)

  For large trees (≥2" DBH): species-specific calculations are performed

    Calculate stemwood (SW) = EXP_{10} (***a*** + ***b*** (log (DBH)) [***a*** and ***b*** are species-specific constants]

    Calculate species-specific ratios of leaf:SW, branch:SW, twig:SW, bark:SW

    Use ratios • bole C to get C pools of leaf, twig, branch, and bark

    Root C = 2 * leaf C

    Stem C = (bole + branch + twig + bark) C. (In BGC, stem C ≠ SW.)

    (Note that the leaf C pool calculations do not consider crown information.)

  For shrubs: leaf, root, and stem biomass = f (% cover, HT)

  For grass: leaf and root biomass = f (% cover) [grass has no stem]
- Calculate crown widths (CW)

  For small trees (< 3.5" DBH): CW=f (HT, CL, BA, Sp)

  For large trees (≥3.5" DBH): use Moeur's (1981) equations: CW=f (DBH, HT, CL, Sp)
- Calculate crown volumes (assume right circular cones for trees; cylinders for grasses and shrubs); calculate leaf density

- Define canopy zones

  Canopy zones are the layers through which incoming radiation will be absorbed and attenuated. One of two methods is used. (The user defines which method in SITE.dat [flagged via parameter S(7)])

    Method one vertically divides all crowns at boundaries defined by the tops and bottoms of all entity crowns (resulting in at most 2n-1 canopy layers, where n = the number of entities per hectare).

    Method two divides all crowns at evenly spaced boundaries; the thickness of the zones is defined in the SITE.dat file (by parameter S(8), which is only used if S(7) = 1).

- Calculate—by canopy zone—(all-sided) LA and (all-sided) LAI (LA / crown width at base of zone), using leaf biomass (calculated above) and (life-form specific) specific leaf area (m^2/kg; user defined in BETA.dat).

3) For each day:

- Read climate file; calculate other climatic variables not entered in the climate file or in SITE.dat.

  Avg 24-hr air temp (°C): mean of daily max and min air temp

  Atmospheric pressure (Pa): f (elevation, avg day air temp)

  Avg daytime air temp (°C): f (avg 24-hr and daily max air temps)

  Avg nighttime air temp (°C): mean of avg daytime and daily min air temps

  Vapor pressure deficit (VPD) (mbar): f (avg daytime air temp, RH)

  Absolute humidity deficit ($\mu g/m^3$): f (VPD, avg daytime air temp)

  Day length (s): f (JD, latitude)

  Soil temperature (°C): f (previous day's avg 24-hr air temp)

- Calculate absorbed radiation by entity-layer: Two radiation terms calculated. One (RAD1) for ET and snowmelt; another (RAD2) for PSN and conductance.

  RAD1 = f (Radiation [from climate file input], albedo).

  RAD2 = f (JD, slope, transmissivity, aspect, latitude) and uses the following constants: solar constant (1365 W/m^2); photosynthetic photon energy (4.55 µmol/J); PAR fraction (50 percent)

  Attenuate radiation through canopy layers:

    Radiation absorbed by layer = f (incoming radiation, one-sided LAI of layer, light extinction coefficient, area of canopy layer base)

- Calculate site moisture balance for the two soil layers (each layer = ½ soil depth).

  Add precipitation (less the evaporated precipitation and that intercepted by leaves), if applicable.

  Melt some snowpack or evaporate some soil moisture, if applicable.

  Deduct yesterday's transpiration by layer.

  Remove excess water if layers become saturated.

4) Entity loop: for each entity:

- Turn leaves 'on' (= "active") or 'off' (= "inactive") based on day (hard-coded: trees are always "on"; shrubs are on JD 120-260; grasses are on JD 120-210.

- Calculate site occupancy (for currently "active" entities).

Site occupancy = ratio of LA (entity) : total site (active) LA, modified by percentage bare ground (input by user in SITE.dat)

5) Crown layer loop: for each crown layer, from top to bottom:

- Calculate soil water potential (SWP) for each of two soil layers → used for stomatal conductance (next step).

  SWP = f (soil texture [% clay, sand], soil depth, volume of water present)

  Volume of water present = f (volume of water present at beginning of day [see "Calculate site moisture balance" above], amount transpired by the canopy layer above the current canopy layer, and size of "water bucket" available to plant, which is a function of the entity's site occupancy—see above)

  Note: The calculation of ***site*** *moisture balance in Step (3) (above) effectively equilibrates each entity's water buckets to the site at the beginning of each day. During the day, as photosynthesis, transpiration, and respiration are simulated by canopy zone, each entity's water bucket gets incrementally drawn down. SWPs are recalculated each time this loop gets re-entered. Thus, the upper-most crown, receiving the most light, has access to the most water; PSN (per unit LA) for subsequent layers may be diminished because of transpiration from the layer above.*

- Calculate leaf water potential (LWP).

  LWP is used for PSN and stomatal conductance. (Conductance is used to calculate transpiration—see below.)

  LWP = f (SWP, minimum LWP, LWP at stomatal closure, canopy layer height)

- Calculate stomatal conductance (of water), for use in transpiration calculation (below). (Stomatal conductance is *not* used for PSN.) The following terms modify stomatal conductance. Each term is a function of a number of parameters and/or variables, as noted):

  TEMP = f (avg daytime air temp, optimum PSN temp, max PSN temp)

  LWP = f (SWP, minimum LWP, LWP at stomatal closure)

  Atmospheric CO_2 concentration (hard-coded at 350 ppm)

  Daily minimum temperature

  VPD = f (VPD, VPD at stomatal closure)

  RAD2 (see above)

  LAI (of crown layer)

  The following constants from the BETA.dat file

  Ratio of all sided to 1-sided LAI

  Slope of g_s (stomatal conductance) vs. PAR

  Canopy light extinction coefficient

  Maximum leaf conductance

- Calculate transpiration. Remove water from soil.

  Transpiration = f (Conductance [see above], day length, average daytime air temperature, VPD, RAD2, boundary layer conductance)

  Water is incrementally removed via transpiration from an entity's water bucket after PSN, respiration, and transpiration have been simulated for each crown layer. For large trees, water *is removed from the bucket-layer with the higher (less negative) SWP. For small trees, shrubs, and grass, soil water is only available from the upper bucket-layer.*

- Calculate gross photosynthesis (PSN). Accumulate C.

  PSN = f (max PSN, LWP, LWP at stomatal closure, min LWP, optimum PSN temp, max PSN temp, average daytime air temp, atmospheric CO_2 concentration, atmospheric pressure, RAD2, canopy light extinction coefficient, ratio of all-sided to 1-sided leaf area, area of canopy layer bases)

  Note: Photosynthesis is only indirectly affected by the amount of water transpired. The simulation of water dynamics in FVS-BGC affects photosynthesis via its affect on leaf water potential.

- Calculate maintenance and growth respiration. Calculate net PSN.

  <u>Maintenance respiration:</u>

  Leaf: f (“base” maintenance leaf respiration rate—at 0 °C—maintenance respiration coefficient, avg nighttime air temp, nighttime length, leaf C)

  Stem: f (“base” maintenance stem respiration rate [at 0 °C], coefficient for maintenance respiration, avg 24-hr air temperature, stem C—for trees, only a portion of stem C respires)

  Portion of tree stem C respiring = EXP (Crown ratio • LN (Stem C))

  Root: f (“base” maintenance root respiration rate (at 0 °C), coefficient for maintenance respiration, soil temp, root C

  <u>Growth respiration:</u>

  Growth respiration by tissue = FC • allocation fraction • growth respiration fraction. (Terms of equation defined below.)

  FC = Fixed Carbon = Gross PSN minus maintenance respiration

  Growth allocation fractions are initialized (by user) in BETA.dat. They are recalculated at the end of the year (see (6) below). Growth allocation fractions define the proportion of total net fixed C going to each tissue pool: leaf, stem, root.

  Growth respiration fractions (by tissue) are input by user in BETA.dat (amount of C respired per unit of C used for growth).

- Growth (in terms of C increment by tissue pool) for the day is represented by FC • allocation fraction • (1-growth respiration fraction). This increment is stored, and is added to plant C (or biomass) pools at the end of the year (see below).
- Repeat for entity’s next crown layer (Go back to (5))
- Repeat for next entity (Go back to (4))
- Repeat for next day (Go back to (3))

<u>6) At end of year</u>

- Calculate net C fixed by entity (sum of daily increments; see above).
- Allocate new C to appropriate tissue pools (leaf, stem, root), based on allocation ratios (user-defined for year 1; recalculated (see below) for each subsequent year).
- Recalculate new bole volume based on new stem C using:

  Fraction of stem C in bole = ***a*** + ***b*** (log (DBH)), where ***a*** and ***b*** are species-specific constants, derived from same data used to derive equations in (2) above.

- Update entity dimensions.

  New HT = f (old HT, new bole volume)

New DBH = f (old DBH, new bole volume)

Note: BGC uses different functions for large and small trees. Parameters for large trees are species-specific. Shrubs reach a maximum height of 1 meter. Grasses do not increase in height. Shrubs and grasses increasing in biomass generate more cover (crowns get wider).

For crown update, see below.

- Calculate new C allocation ratios ***for each entity*** for use next year. These allocation ratios will dictate how next years' fixed C will be apportioned among leaf, stem, and root pools.

  Leaf C allocation fraction = f (this year's SWPs, number of days leaves are active, max ratio of leaf C**:**(leaf + root) C, LWP at stomatal closure, leaf turnover rate, water stress integral fraction, leaf growth respiration fraction, leaf C, total net PSN (for this entity) for the year).

  Root C allocation fraction = f (this year's SWPs, number of days leaves are active, max ratio of leaf C**:**(leaf + root) C, LWP at stomatal closure, new leaf allocation fraction).

  Stem C allocation fraction = 1 – (new root + new leaf) fractions.

  Note: allocation to roots increases as water stress over the year increases (water stress is a function of this year's SWPs, the number of days the leaves are active, and the LWP at stomatal closure). Allocation to leaf increases as water stress decreases. The leaf C allocation fraction is constrained to be ≤ [2 • root fraction] (user-definable via maximum ratio of leaf C **:** *(leaf + root) C [parameter B2(19)]).*

- Calculate and apply turnover (senescence). Turnover ***does not*** affect HT or DBH dimensions; it ***does*** affect crown dimensions.

  Note: Turnover occurs after growth, thus user-supplied turnover rates (in BETA.dat) are (annual) ***post-growth*** *percentages. Thus, user-defined turnover rates of 100 percent will effectively kill an entity. Assuming an entity replaces (via growth) what deciduous leaves it looses (via turnover) in an "average" year (in the model), a turnover rate of 50 percent would effectively represent complete leaf turnover (i.e., would represent a completely deciduous species).*

- Update biomass and C pools for turned-over tissue.

- Recalculate crown dimensions based on new height and new biomass of leaf.

  If leaf biomass has increased, increase crown length by HT increment.

  If leaf biomass decreased, remove crown from tree base (keeping beginning-of-year leaf density and crown apex angle the same); add HT increment to crown length; if grass or shrub, reduce percentage cover.

- Determine if entity survives. Death of an entity results from leaf biomass decreasing over time, which occurs when turnover rates exceed growth rates. (Growth *per se* cannot be negative; if respiration exceeds PSN, *net* PSN is set to zero.)

  For trees, entities die if A) crown ratios reach 0.02; or B) if maintenance respiration exceeds photosynthesis for ten years in a row.

  For shrubs and grasses, entities die if their percent cover reaches zero. Note that—for grasses only—the current year's percent cover is determined *before* the current year's leaf turnover is applied. (This year's "turned over" leaf is assumed to still provide cover this year.) Note that percent cover will only reach zero if turnover rates are set to 100 percent.

  Note: since turnover is a percentage of current year's biomass, post-turnover leaf biomass always will be greater than zero (if turnover rates are less than 100 percent). However, over time leaf biomass may become extremely small. Hence, percentage cover of understory will never reach exactly zero, hence understory entities will not die (if leaf turnover rates are < 100 percent). Thus, understory vegetation may be simulated over time to have a percentage cover so small that their simulated dynamics are essentially insignificant, yet they remain as viable entities, *such that if conditions were to change (e.g., the stand thinned, or a more favorable climate imposed), their biomass may increase.*

- If entity dies, set PROB to zero (for input to FVS); remove the entity from FVS-BGC's entity list; report information to DEAD.out.
- Convert tree entity growth increments (HT, CR, DBH) to FVS-ready values.
- Run another year, or, if end of cycle, return control to FVS, and, if invoked, input growth increments (and PROB) to FVS.

7) Next cycle:

- Update entity list from FVS.

If BGC is driving growth, only update BGC's entity list by adding new entities created via the Cover and/or Regeneration and Establishment extensions of FVS, and by changing PROBS of existing tree entities, if trees were thinned this cycle in FVS.

If FVS is driving growth, completely update (i.e., re-initialize) BGC entity list from FVS treelist. (The FVS treelist will manifest all of FVS's projected tree growth and mortality from the previous cycle).

Note: If BGC is driving growth and mortality (in FVS), the updating that FVS performs on BGC's entity list will only reflect changes FVS made to its treelist as a result of regeneration, establishment, and/or management actions. Any FVS-simulated background mortality and/or insect and disease projections were over-ridden by BGC at the end of the previous cycle.

ABBREVIATIONS AND ACRONYMS USED IN APPENDIX A

BA	Cross sectional basal area at breast height (4.5 feet) (outside bark).
BGC	Biogeochemical cycles: the FVS-BGC extension.
C	Carbon (usually referring to a mass of carbon belonging to a particular tissue pool of an entity.
CL	Crown length.
CR	Crown ratio (proportion of a tree's height that is crowned).
CW	Crown width (usually refers to the width of an entity's crown base, but in some cases may refer to the base of a crown *layer's* base.
DBH	Diameter at breast height (4.5 feet) (outside bark).
DF	Douglas-fir.
ET	Evapotranspiration (evaporation plus transpiration).
EXP ( )	The quantity in parentheses is the exponent of ***e***.
EXP_{10} ( )	The quantity in parentheses is the exponent of 10.
f ( )	"A function of" what follows in parentheses.
FC	Fixed carbon. Mass of carbon accumulated via photosynthesis, *after* accounting for maintenance respiration, but *before* accounting for growth respiration.
FVS	Forest Vegetation Simulator, a tree growth and yield model.
g_s	Stomatal conductance (mm/s).
HT	Height.
JD	Julian day (the days of the year numbered consecutively 1-365).
LA	Leaf area (m^2) (usually, but not always, all-sided).
LAI	Leaf area index. Leaf area divided by some reference area, either the crown width, or the unit reference area (in the case of BGC, one hectare; for FVS, one acre).
log ( )	The logarithm (base 10) of the quantity in parentheses.
LN ( )	The natural logarithm (base ***e***) of the quantity in parentheses.
LP	Lodgepole pine.
LWP	Leaf water potential.
Max	Maximum.
Min	Minimum.
PAR	Photosynthetically active radiation; (radiation of wavelengths 400-700nm).
PP	Ponderosa pine.
PROB	The number of trees per unit area represented by a tree record or entity.
PSN	Photosynthesis.
RH	Relative humidity.
Sp	Species.
SW	Biomass of stemwood, as used in the biomass ratio equations. This variable is an "intermediate" value; it does *not* represent what BGC uses for the stem C pool.
SWP	Soil water potential.
Temp	Temperature.
TPH	Trees per hectare.
VPD	Vapor pressure deficit.
WL	Western larch.

APPENDIX B:
USING MTCLIM (A MOUNTAIN CLIMATE SIMULATOR)

MTCLIM (Hungerford et al. 1989) is a program that extrapolates base station weather data to other sites, thus "correcting" the base station data for the elevation, slope, and aspect of the site for which weather data are desired. It was developed for use in the Northern Rocky Mountains. The resulting climate output file yields a more realistic representation of site weather than would be represented by the base station. A brief description follows. For further information, refer to Hungerford et al. 1989, and the NTSG website (see the References and Literature Cited section)).

The version of MTCLIM that is currently compatible with FVS-BGC is *not* the most up-to-date version; however, as of this writing, this older version is the *only* version compatible with FVS-BGC. This FVS-BGC-compatible version of MTCLIM is no longer available at the NTSG website; users running the FVS-BGC may obtain an FVS-BGC-compatible version of MTCLIM along with the FVS-BGC extension (see Appendix E

MTCLIM requires two input files: the initialization file (Table B1) and the base station daily weather data (Table B2). These two files, plus the MTCLIM executable program, must reside in the same directory on the user's computer. Each of the two input files is discussed below. Output from MTCLIM, which is used as input to FVS-BGC, is presented in Appendix C.

Initialization File

The initialization file (Table B1) differs slightly from that described in Hungerford et al. (1989). First, there is an added line (line 5), for the user to enter the name of the (MTCLIM) output file to be used as input into FVS-BGC. This output file will be produced in addition to the usual MTCLIM output file (named in line 4). The other difference that users must be aware of is that *FVS-BGC requires metric (SI) units*; therefore, MTCLIM must process all units accordingly. Although MTCLIM offers the user the option, the user ***must***: (1) provide input data (in the base station weather data file) in SI units (temperatures in °C, precipitation in cm); (2) set line 6 to "SI"; and (3) provide data in lines 14, 15, 19, 20, 21 (if applicable), and 26-30 in metric units (°C for temperature, cm for precipitation, and m for elevation). Also, FVS-BGC requires that dates be expressed in Julian days[13] rather than month and day; therefore, line 11 must be set to "Y," and the corresponding input data in the base station climate input data file (discussed below) must be in the Julian day format.

[13] Julian days are the days of the year numbered consecutively 1-365 (January 1 = Julian day 1). In MTCLIM and FVS-BGC, all years have 365 days—leap days (Feb 29) are ignored.

Table B1. Description of data in the MTCLIM's initialization file. Line numbers are provided here for reference purposes; they are not part of the file.

File Line #	Example Value	Description
1 2	The first two lines of this file are for comments, while MTCLIM allows a user to specify English or SI units (line 6), FVS-BGC requires all need to be SI.	
3	CLIM_IN.MTC	Input climate data filename
4	WEATHER1.OUT	Output data filename (not used by FVS-BGC)
5	CLIMATE.CLM	FVS-BGC-ready output filename
6	SI	Units (English or SI—metric—[E or SI]: for BGC, this must be SI.
7	N	Dewpoint temperature supplied [Y or N]
8	1	Number of PPT stations [1 or 2]
9	N	Use threshold radiation? [Y or N]
10	T	Report total (T) or average (Q) radiation? [FVS-BGC requires T]
11	Y	Use Julian day in place of month and day?[FVS-BGC requires Y]
12	365	Number of days to output [Anything other than 365 will cause errors]
13	39.38	Base station latitude
14	2913	Site elevation [m]
15	2500	Base station elevation [m]
16	0	Site aspect [degrees; North = 0°]
17	0	Site slope (%)
18	9.7	Site LAI (all-sided)
19	54.76	Site PPT isohyet (mean annual PPT at site [cm]
20	54.76	Base station 1 PPT isohyet (mean annual PPT at base station [cm])
21	0	Base station 2 PT isohyet [optional] [cm]
22	0	Site east horizon (degrees above horizontal)
23	0	Site west horizon (degrees above horizontal
24	0.2	Site albedo [decimal fraction: e.g., 0.2 = 20 percent]
25	0.65	Transmissivity coefficient
26	0.45	Average daytime temperature coefficient
27	6.4	Average temperature lapse rate (°C/km)
28	8.2	Maximum temperature lapse rate (°C/km)
29	4.5	Minimum temperature lapse rate (°C/km)
30	2.7	Dewpoint lapse rate (°C/km)

PPT = precipitation.

All data must be in columns 1-12. Lines 1 and 2 are for comments, as are columns 13 and up in all other lines. The first two lines of data in the initialization file are for comments; the program will not read any data from these two lines. Data entry begins on line 3, and ends on line 30. Data must be entered in columns 1-12. Columns 13 and up (for all lines) are for comments. Line 7 informs the program if dewpoint temperatures are provided in the input data file. They are optional. If they are not provided, the model will use the daily minimum temperatures as the dewpoint temperature. Line 8 allows for the optional inputting of a second set of precipitation data (from a separate base station). If line 8 is set to 2, line 21 must contain the appropriate value, and the data must exist in the input climate file. If line 9 is set to yes (Y), calculations of day length, used in the calculations of total and average radiation, will be truncated such that radiation incoming during the early and late part of the days, when incoming radiation is <70 W/m^2, will be ignored from the radiation calculations (hence radiation projections will be lower if line 9 is "Y"). FVS-BGC requires total daily radiation; therefore line 10 must be set to "T". Line 12 should be some whole-number multiple of 365 days. LAI (line 18) is used in the maximum temperature calculations.

For FVS-BGC compatibility, all units must be metric (SI), and line 6 set to "SI". FVS-BGC will use the output file named in line 5. A second precipitation base station data set (lines 8 and 21) is optional. The provision of dewpoint temperatures (line 7) is optional (see climate file section). Line 25 is the clear sky transmissivity at sea level. For discussion of line 26 (or any of the other parameters), see Hungerford et al. 1989.

Climate File

The base station weather file must contain—at a minimum—four columns of data: Julian day, daily maximum air temperature (°C), daily minimum air temperature (°C), and daily precipitation (cm) (Table B2). There should be one row of data for each day of the year. More than 365 days in the input file will yield erroneous transmissivities beyond year one. For leap years (366 days) one day needs to be removed.

There can be no missing values. If values are missing, employ statistical methods or expert opinion to fill in the missing values. The reading-in of the data by the program is open-formatted, so the particular fields do not need to be in particular columns; they may be space or column delimited (and may have any number of blank spaces between entries.) The file should contain no headings or comments.

Table B2. Excerpt from a climate file used as input to MTCLIM. Column 1 is Julian day; column 2 is the daily maximum temperature (°C), Column 3 is the daily minimum temperature (°C); column 4 is the daily precipitation (cm). This example demonstrates the minimum number of fields (columns) required by MTCLIM. Alternatively, dewpoint temperatures may also be provided by the user (and if so, must be entered in column 4), as may precipitation data from a second base station (which, if provided, must be in the final column). Data are to be space- or comma-delimited.

```
1   -0.56  -21.11    0.53
2   -0.56  -12.22    0.00
3    3.89  -14.44    0.00
4    0.56  -19.44    0.03
5   -2.78  -22.22    0.00
6   -1.67  -17.78    1.04
```

If entering dewpoint temperatures, they should be in the fourth field, after the daily minimum temperature, and before precipitation. If entering dewpoint temperatures, line 7 of the initialization file should be set to "Y". (Conversely, line 7 of the initialization file should be set to "N" if dewpoint temperatures are not provided.) Dewpoint temperatures are used in the calculations of daily relative humidity. If dewpoint temperatures are not provided, dewpoint temperatures will be set equal to the daily minimum temperature.

If using two base stations to project precipitation, enter the second station's precipitation data in the last (fifth or sixth) field. Also, be sure to correctly define lines 8 and 21 in the initialization file.

APPENDIX C: FVS-BGC INPUT FILES

This appendix presents example excerpts from the three input files required by FVS-BGC: the climate file (output from MTCLIM); the SITE.dat file (containing site parameters); and the BETA.dat file (containing life form parameters).

CLIMATE.clm file

The climate file provides the daily moisture and radiation balances that FVS-BGC uses to drive growth. The seven fields of required data are: Julian Day (number 1-365—with no leap days), Maximum Air Temperature (°C), Minimum Air Temperature (°C), Relative Humidity (%), Radiation (kJ/m^2), Precipitation (mm), and Transmissivity (decimal fraction). The units must be presented in the units indicated. There must not be any missing values. ***MTCLIM will generate an appropriately formatted climate file.*** The format of the file must be as follows:

REQUIRED COLUMN NUMBERS IN WHICH EACH FIELD'S DATA MUST RESIDE.

NUMBER IN PARENTHESES IS THE NUMBER OF DECIMAL PLACES IMPLICITLY READ (IF A DECIMAL POINT IS NOT EXPLICITLY PROVIDED).

Julian Day	Max. Temp. (°C)	Min. Temp. (°C)	Rel. Hum. (%)	Tot. Rad. (kJ/m2)	PPT (mm)	Transm. (%/100)
2-4 (0)	**7-14 (2)**	**15-22 (2)**	**23-30 (2)**	**31-40 (2)**	**41-48 (2)**	**49-56 (5)**
THE FORTRAN FORMAT ITEMS FOR THE READING-IN OF THIS DATA IS: 1X,I3,2X,3(F8.2),F10.2,F8.2,F8.5						

Table C1. Example excerpt from CLIMATE.clm file used as input to FVS-BGC (and was output by MTCLIM). Notice that—in comparing Table C1 with Table B2—temperatures in this table have been adjusted for elevation; precipitations are identical because the precipitation isohyets (lines 19 and 20 in MTCLIM's initialization file—Table B1) were identical (i.e., precipitation was simulated in MTCLIM identically for the base station and the site.).

```
 1     -3.05  -22.97   30.56  10319.67    5.30 0.79190
 2     -3.05  -14.08   53.92   8942.77    0.00 0.71482
 3      1.40  -16.30   36.85   7941.73    0.00 0.65558
 4     -1.93  -21.30   32.07   9974.79    0.30 0.77305
 5     -5.27  -24.08   32.17    742.17    0.00 0.10000
 6     -4.16  -19.64   40.51   1497.90   10.40 0.17802
```

SITE.dat file

The SITE.dat file (Table C2) contains site parameters needed by FVS-BGC. Most of these parameters pertain to the site's soils, and thus will directly influence water dynamics in the simulation. Unlike the parameters in the BETA.dat file (see next section), which tend to have a wider ecological range of applicability, most parameters in this file are site-specific. Accordingly, these parameter values ought to accurately depict the site under consideration, and users should be careful in assigning values. The file should contain 16 rows of data. Values are read from the first 10 columns of each row. If no decimal point is explicitly entered, the value is read to five decimal places (e.g., 25 would be read in as 0.00025). Comments may exist in columns eleven and up (as in the example below). Because parameters S(10) and S(13) are not used, their fields can be left blank but their rows must not be deleted. Parameter S(3) is optional—to have FVS-BGC calculate this value (based upon soil texture), initialize it to zero. ***(We recommend that users let FVS-BGC calculate this parameter.)*** For S(4), note that 1 inch of water (on a hectare) equals 254 cubic meters. Note also that the algorithm used to calculate soil water potential (which is based on soil texture and amount of water present; Saxton et al. 1986) is valid for soils with textures in the following ranges:

$5\% \leq \%\text{ sand} \leq 30\%$ with $8\% \leq \%\text{ clay} \leq 58\%$, and

$30\% \leq \%\text{ sand} \leq 95\%$ with $5\% \leq \%\text{ clay} \leq 60\%$.

Table C2. Example excerpt from the SITE.dat file. See chapter 2 for description.

```
1450.0   S(1) INITIAL SOIL WATER CONTENT (m3/ha)
1.0      S(2) SOIL DEPTH (m)  1.3
0.51     S(3) MAX. VOL. WATER CONTENT (m3/m3) [optional]
500.0    S(4) VOLUME OF WATER IN INITIAL SNOWPACK (m3/ha)
0.00065  S(5) SNOWMELT COEFFICIENT (m/degree C/day)
0.2      S(6) ALBEDO (PROPORTION OF RADIATION REFLECTED)
1.0      S(7) CROWN ZONE FLAG (1.=DEPTH METHOD,  0.=BY TREE)
1.0      S(8) CROWN ZONE DEPTH (m)
0.0      S(9) BARE GROUND (%)
0.0      S(10)(NOT USED)
1.0      S(11)STARTING YEAR ! USE 1!
40.0     S(12)PERCENT SAND
40.0     S(13)PERCENT SILT  !CURRENTLY NOT USED
20.0     S(14)PERCENT CLAY
1.0      S(15)PPT MULTIPLIER VARIABLE
0.9      S(16)PSN MULTIPLIER
```

BETA.dat file

The BETA.dat file contains numerous physiological parameters used by FVS-BGC. The parameter values reported below have been derived from extensive data; accordingly, users are cautioned against making injudicious adjustments to these parameters. Users may refer to White and others (2000) for additional sources of relevant published values. As with the parameters in SITE.dat, decimal points should be explicitly entered for all values, and *no field should be left blank*. Table 7 (in section 2.1.3) shows which simulated process uses which parameter. All of these parameters are also referred to in the detailed description of FVS-BGC in Appendix A.

The first 13 parameters are life-form dependent; accordingly, these first 13 are dimensioned by life form (e.g. there are three B1(1) parameters: B1(1,tree), B1(1,shrub), and B1(1,grass). For these first thirteen, the three life form-specific values are all entered on one line. The first value is for trees, the second for shrubs, and the third for grasses. *The first value must reside in columns 1-8, the second in columns 10-17, and the third in columns 19-26*. If no decimal point is entered, the value will be read to four decimal places (e.g. 16 will be read as 0.0016). (Fortran format items = 3(F8.4,1X))

The second set of twenty-two parameters is life form independent; one value is used for all life forms. Values must be entered into columns 1-8; no decimal place is assumed (Fortran format items = F8.0).

Of all the parameters in this file, six currently are not used [B1(6), B1(12), B2(9), B2(13), B2(21), and B2(22)]. Even though these parameters are not used, *the field must still contain a value* in order for the program to successfully read the file.

Parameters B2(11, 12, and 14) (first year carbon allocation ratios for leaf, stem, and root, respectively) should sum to one. These three parameters are used for trees and shrubs only. For grasses, the allocation ratios (for year one) are hard-coded at 50 percent leaf, 50 percent root (simulated grass has no allocation for stems).

Table C3. Example BETA.dat file. For a description, see the text above and in section 2.1.3. (The comma delimiters (lines 1-13) are not required.)

```
 00.0016,  0.0016,  0.006   B1(1) MAX LEAF CONDUCTANCE (m/s)
  0.5   ,  0.5   ,  0.5     B1(2) MINIMUM LWP (-MPa)
   .1   ,   .1   ,   .01    B1(3) BOUNDARY LAYER CONDUCTANCE (m/s)
   .0002,   .0004,   .0044  B1(4) LEAF RESP. (kgC/day at 0 C)
   .0002,   .0002,   .0044  B1(5) STEM RESP. (kgC/day at 0 C)
   .0002,   .0002,   .0003  B1(6) COARSE ROOT RESP. (not used)
   .0004,   .0011,   .0044  B1(7) FINE ROOT RESP. (kgC/day at 0 C)
  4.0   ,  4.0   ,  6.0     B1(8) MAX PSN RATE (umol/m2/s)
 25.0   , 20.0   , 10.0     B1(9) LEAF TURNOVER (%/yr)
  0.0   , 20.0   , 98.0     B1(10)STEM TURNOVER (%/yr)
 40.0   , 80.0   , 50.0     B1(11)ROOT TURNOVER (%/yr)
 33.0   , 18.0   , 17.0     B1(12)LEAF LIGNIN CONC. (%) (not used)
 25.0   , 35.0   , 25.0     B1(13)   SPECIFIC LEAF AREA (m2/kgC)
0.0005         B2(1)    RAIN INTERCEPTION COEFF. (m/lai/day)
-0.5           B2(2)    CANOPY LIGHT EXT. COEFF.
1.65           B2(3)    LWP AT STOMATAL CLOSURE (-MPa)
25.0           B2(4)    VPD AT STOMATAL CLOSURE (mbar)
20.0           B2(5)    OPTIMUM TEMP PSN (degree C)
45.0           B2(6)    MAX TEMP. PSN (degree C)
0.35           B2(7)    LEAF GROWTH RESP. FRACTION
0.30           B2(8)    STEM GROWTH RESP. FRACTION
0.00           B2(9)    COARSE ROOT GROWTH RESP. FRACTION (not used)
0.35           B2(10)   FINE ROOT GROWTH RESP. FRACT. (for all roots)
0.15           B2(11)   LEAF CARBON ALLOC. FRACTION
0.35           B2(12)   STEM CARBON ALLOC. FRACTION
0.00           B2(13)   COARSE ROOT CARBON ALLOC. FRACTION (not used)
0.50           B2(14)   FINE ROOT C ALLOC. FRACT. (for all roots)
2.3            B2(15)   RATIO ALL-SIDED LAI TO 1-SIDED LAI
0.01           B2(16)   SLOPE OF gs vs PAR ( (mm/s) / (uE/m2/s) )
0.069          B2(17)   COEFF. FOR MAINTENANCE RESP. (Q10=2.0)
0.50           B2(18)   FRACTION OF C IN DRY MATTER (kgC/kg dry wt)
0.66           B2(19)   MAX RATIO OF (LEAF C) TO (LEAF + ROOT C)
0.20           B2(20)   WATER STRESS INTEGRAL FRACTION
0.85           B2(21)   STEM/COARSE ROOT ALLOCATION RATIO (not used)
0.25           B2(22)   FRACT. OF TOTAL STEM C IN BRANCHES (not used)
```

APPENDIX D: FVS-BGC OUTPUT FILE EXCERPTS

This appendix contains excerpts form the five output files described in section 2.2.

Table D1. Excerpt from FVS-BGC output file YRSTAND.out. Contains year-end stand-level summary data. This file will be produced for every year and every cycle of the simulation, including year zero of each cycle (containing the beginning-of-cycle values). The header row is printed at the beginning of each cycle.

YRSTAND.OUT

FVS CYC	YR	YRPSN (kgC/ha)	YRTRANS (m3/ha)	YRMRESP (kgC/ha)	YRGRESP (kgC/ha)	LAI_GR (m2/m2)	LAI_SH (m2/m2)	LAI_SM (m2/m2)	LAI_LG (m2/m2)	SITELAI (m2/m2)	TSTEM (kgC/ha)	CCF	ABSRAD (GJ/ha)
1	0	0.00	0.00	0.00	0.00	0.05	0.22	0.20	11.55	12.02	109177.16	197.3	0.
1	1	10297.52	1708.53	3594.00	2644.09	0.03	0.13	0.19	9.77	10.12	110584.28	197.3	32787.
1	2	12357.88	2356.76	3423.94	3045.41	0.01	0.11	0.21	9.87	10.19	112983.22	199.8	31008.
1	3	13088.18	2395.30	3351.39	3422.19	0.01	0.09	0.22	10.07	10.38	116048.62	203.4	32270.
1	4	13193.91	2435.63	2774.18	3577.85	0.00	0.07	0.06	9.88	10.01	99801.59	173.0	32398.
1	5	12907.33	2402.86	2448.88	3598.95	0.00	0.05	0.06	9.73	9.85	87521.64	145.0	33229.
1	6	12221.88	2629.96	2297.36	3420.21	0.00	0.04	0.06	9.95	10.05	90729.00	148.2	34312.
1	7	11273.59	2284.56	2496.38	3120.31	0.00	0.03	0.06	9.92	10.00	93351.99	151.1	34891.
1	8	13550.73	2644.06	2342.49	3901.17	0.00	0.02	0.05	10.96	11.04	96308.03	153.3	35354.
1	9	12453.97	2546.26	2529.10	3540.07	0.00	0.02	0.05	11.33	11.40	99319.55	155.8	39517.
1	10	13477.45	2730.34	2467.36	3876.53	0.00	0.01	0.04	12.19	12.24	102157.70	158.3	40115.

FVS CYC	YR	YRPSN (kgC/ha)	YRTRANS (m3/ha)	YRMRESP (kgC/ha)	YRGRESP (kgC/ha)	LAI_GR (m2/m2)	LAI_SH (m2/m2)	LAI_SM (m2/m2)	LAI_LG (m2/m2)	SITELAI (m2/m2)	TSTEM (kgC/ha)	CCF	ABSRAD (GJ/ha)
2	0	0.00	0.00	0.00	0.00	0.00	0.01	0.04	12.19	12.24	102206.69	160.6	0.
2	1	12655.09	1871.24	2796.11	3582.20	0.00	0.01	0.03	10.86	10.89	104478.05	160.6	38343.
2	2	14606.29	2523.94	2919.47	4083.97	0.00	0.00	0.02	11.75	11.78	107667.62	162.1	37288.
2	3	15394.97	2573.42	2974.37	4314.28	0.00	0.00	0.02	12.38	12.40	111411.41	164.5	38351.
2	4	15767.38	2572.07	3027.41	4435.79	0.00	0.00	0.01	12.91	12.92	115299.96	167.2	39391.
2	5	15611.33	2555.58	3092.56	4447.09	0.00	0.00	0.01	13.24	13.25	119036.20	170.0	40300.
2	6	14321.61	2841.13	2878.10	4065.61	0.00	0.00	0.01	13.32	13.33	122293.83	172.6	40953.
2	7	12924.24	2346.26	3088.21	3667.78	0.00	0.00	0.01	13.07	13.08	124737.45	174.7	41438.
2	8	16018.07	2841.60	2866.21	4664.88	0.00	0.00	0.00	14.19	14.20	127869.52	176.1	41429.
2	9	14476.95	2739.97	3027.03	4197.83	0.00	0.00	0.00	14.24	14.25	130683.41	177.6	45573.
2	10	15121.44	2870.43	2903.81	4397.11	0.00	0.00	0.00	14.70	14.71	133295.66	179.0	46045.

Table D2. Excerpt from FVS-BGC output file DAYSTAND.out. Contains daily stand-level summary data. Each line represents one day. Header rows are printed at the beginning of each FVS cycle. All values are for the end of each day. The table is printed for all years and all cycles.

DAYSTAND.OUT

FVS CYC	YR	JD	PPT (mm)	TMAX (C)	TMIN (C)	PSN (kgC/ha)	TRANS (m3/ha)	MRESP (kgC/ha)	SWP1 (-MPa)	SWP2 (-MPa)	RADTOP (kJ)	RADBOT (kJ)	SITELAI (m2/m2)
1	1.	1	5.30	-3.05	-22.97	0.00	0.01	2.66	4.31	4.31	8255.74	3404.60	12.02
1	1.	2	0.00	-3.05	-14.08	0.00	0.01	3.89	4.30	4.24	7154.22	2950.34	12.02
1	1.	3	0.00	1.40	-16.30	0.00	0.01	4.39	4.30	4.18	6353.38	2620.09	12.02
1	1.	4	0.30	-1.93	-21.30	0.00	0.01	3.62	4.22	4.11	7979.83	3290.82	12.02
1	1.	5	0.00	-5.27	-24.08	0.00	0.01	2.87	4.23	4.10	593.74	244.85	12.02
1	1.	6	10.40	-4.16	-19.64	0.00	0.01	3.15	4.21	4.09	1198.32	494.18	12.02
1	1.	7	2.00	-4.16	-22.42	0.00	0.01	3.06	4.21	4.09	593.74	244.85	12.02

Table D3. Excerpt from FVS-BGC output file YRENTY.out. It contains annual entity-level summary data regarding carbon dynamics. Each line represents one entity. Note that cycle zero (beginning-of-cycle) values are included for carbon pools, but process-related variables are not reported (shown as "0.00"). The header row is printed at the beginning of each cycle. The table is printed for all years and all cycles. Only currently living entities are reported. (If an entity dies, it will no longer be reported in this table; its death will be reflected in the DEAD.out output file.) The ". . ." indicates that the data set has been abbreviated for this presentation.

YRENTY.OUT

FVS CYC	YR	ETY	TREE	SP	PSN (kgC)	TRANSP (m3)	MRESP (kgC)	GRESP (kgC)	LEAF (kgC)	STEM (kgC)	ROOT (kgC)	ABSRAD (GJ)	TURNOVR (kgC)	TPH
1	0.	1	1001	AF	0.000	0.00	0.00	0.00	3.77	88.10	3.77	0.000	0.000	40.
1	0.	2	1003	LP	0.000	0.00	0.00	0.00	2.25	54.27	2.25	0.000	0.000	81.
1	0.	3	1004	LP	0.000	0.00	0.00	0.00	2.86	68.50	2.86	0.000	0.000	70.
1	0.	4	1006	AF	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.000	296.
1	0.	5	1007	ES	0.000	0.00	0.00	0.00	0.01	0.01	0.01	0.000	0.000	148.
1	0.	6	2001	LP	0.000	0.00	0.00	0.00	1.61	39.60	1.61	0.000	0.000	120.
1	0.	7	2002	LP	0.000	0.00	0.00	0.00	2.78	67.21	2.78	0.000	0.000	81.
		.	...											
		.	...											
		.	...											
1	1.	1	1001	AF	11.072	1.86	2.83	3.02	3.40	90.03	3.78	37.649	3.656	40.
1	1.	2	1003	LP	6.416	1.00	1.93	1.69	1.99	55.30	2.16	18.129	2.102	81.
1	1.	3	1004	LP	6.564	0.91	2.31	1.65	2.42	69.47	2.47	15.728	2.453	70.
1	1.	4	1006	AF	0.003	0.00	0.00	0.00	0.00	0.00	0.00	0.014	0.001	296.
1	1.	5	1007	ES	0.024	0.00	0.01	0.01	0.01	0.01	0.01	0.103	0.008	148.
1	1.	6	2001	LP	1.233	0.15	1.52	0.00	1.20	39.60	0.96	2.524	1.043	120.
1	1.	7	2002	LP	2.080	0.27	2.28	0.00	2.09	67.21	1.67	4.642	1.808	81.

Table D4. Excerpt from FVS-BGC output file ENTYLST.out. Contains end-of-year entity attributes. One row represents one entity. The header row is produced annually. This table is produced for all years in all cycles. Only currently living entities are reported. (If an entity dies, it will no longer be reported in this table; its death will be reflected in the DEAD.out output file.) The ". . ." indicates that the data set has been abbreviated for this presentation.

ENTYLST.OUT

FVS CYC	YR	INDX	ID	TRENO	IHT (ft.)	IDBH (in.)	ICR (%/100)	ICW (ft.)	ICOV (%)	HG (ft.)	DG (in.)	CRINC (%)	CUMHG (ft.)	CUMDG (in.)	COVINC (%)	SPECIES
1	1	1	T	1001	45.00	9.50	0.55	10.17		0.27	0.06	-1.60	0.27	0.06		AF
1	1	2	T	1003	52.00	6.70	0.35	5.91		0.26	0.03	-1.06	0.26	0.03		LP
1	1	3	T	1004	58.00	7.20	0.15	4.82		0.21	0.02	-0.48	0.21	0.02		LP
1	1	4	T	1006	1.00	0.00	0.95	1.26		0.07	0.00	-3.54	0.07	0.00		AF
1	1	5	T	1007	2.00	0.00	0.95	1.93		0.20	0.00	-2.26	0.20	0.00		ES
1	1	6	T	2001	54.00	5.50	0.05	2.65		0.00	0.00	-0.46	0.00	0.00		LP
1	1	7	T	2002	65.00	6.70	0.05	3.12		0.00	0.00	-0.46	0.00	0.00		LP
			.	...												
			.	...												
			.	...												

FVS CYC	YR	INDX	ID	TRENO	IHT (ft.)	IDBH (in.)	ICR (%/100)	ICW (ft.)	ICOV (%)	HG (ft.)	DG (in.)	CRINC (%)	CUMHG (ft.)	CUMDG (in.)	COVINC (%)	SPECIES
1	2	1	T	1001	45.27	9.57	0.53	10.13		0.42	0.09	0.42	0.68	0.16		AF
1	2	2	T	1003	52.26	6.73	0.34	5.88		0.36	0.04	0.46	0.62	0.07		LP
1	2	3	T	1004	58.21	7.23	0.15	4.79		0.29	0.03	0.42	0.50	0.06		LP
1	2	4	T	1006	1.07	0.00	0.91	1.31		0.07	0.00	0.56	0.15	0.00		AF
1	2	5	T	1007	2.20	0.00	0.93	2.03		0.25	0.00	0.74	0.45	0.00		ES
1	2	6	T	2001	54.00	5.50	0.05	2.57		0.00	0.00	-0.41	0.00	0.00		LP
1	2	7	T	2002	65.00	6.70	0.05	3.03		0.00	0.00	-0.41	0.00	0.00		LP

Table D5. Excerpt from FVS-BGC output file DEAD.out. This file is written to only when an entity "dies" in FVS-BGC. Each row represents one entity. The header row is produced once per cycle regardless of whether or not mortality has occurred. Entity dimensions reported herein are dimensions at the time of death. Note that, for trees, mortality may result from two causes: crown ratios becoming less than 2 percent or maintenance respiration exceeding PSN for ten years in a row.

DEAD.OUT

```
 FVS YR ID      TREE SP   BD    DBH    HT  CR    TPH    BA  CCF      LA    LEAF    STEM    ROOT
 CYC                     (cm)  (cm)   (m)              (m2)         (m2)  (kgC)   (kgC)   (kgC)
==============================================================================================
   1 10. T      2001 LP  14.9  14.0  16.5 .02  119.7 .02  9.0     2.42    0.10   39.69    0.01
   1 10. T      2002 LP  18.1  17.0  19.8 .02   80.7 .02  8.5     4.13    0.17   67.31    0.02

 FVS YR ID      TREE SP   BD    DBH    HT  CR    TPH    BA  CCF      LA    LEAF    STEM    ROOT
 CYC                     (cm)  (cm)   (m)              (m2)         (m2)  (kgC)   (kgC)   (kgC)
==============================================================================================
   2  1. T      2003 LP  18.7  17.5  18.9 .02   76.1 .02  8.5     3.28    0.13   67.91    0.01
   2  1. T      2004 LP  20.6  19.3  20.5 .02   62.7 .03  8.3     4.47    0.18   87.08    0.02
   2  2. T      2005 LP  22.2  20.9  19.6 .02   53.9 .03  8.2     4.15    0.17   95.80    0.01
   2  2. T      2006 LP  22.7  21.4  19.6 .02   51.3 .04  8.1     4.44    0.18  100.08    0.02
   2  2. T      2007 LP  18.7  17.6  15.6 .02   76.1 .02  8.5     2.58    0.10   56.75    0.01
   2  5. T      2009 ES   0.6   0.0   0.4 .24  148.2 .00  0.0     0.00    0.00    0.00    0.00
   2  6. T      1006 AF   0.6   0.0   0.4 .31  296.4 .00  0.1     0.00    0.00    0.00    0.00
   2  7. T      1007 ES   1.6   0.0   1.0 .42  148.2 .00  0.2     0.02    0.00    0.05    0.00
   2  8. T      2008 AF   2.9   0.8   1.8 .59 1037.4 .00  0.6     0.23    0.01    0.28    0.00

 FVS YR ID      TREE SP   BD    DBH    HT  CR    TPH    BA  CCF      LA    LEAF    STEM    ROOT
 CYC                     (cm)  (cm)   (m)              (m2)         (m2)  (kgC)   (kgC)   (kgC)
==============================================================================================
   3  8. T      4008 AF   1.6   0.0   1.0 .13 1333.8 .00  2.8     0.00    0.00    0.05    0.00
```

APPENDIX E: DATA SOURCES

This appendix lists sources of information and data that users of FVS-BGC might find useful. This list is categorized by subject, and secondarily by region and state.

FVS-BGC

FVS-BGC related downloads will be available at this site:

http://www.fs.fed.us/foresthealth/technology/products.htm

For further information, contact:
Eric L. Smith
USDA Forest Service, FHTET, Suite 331
2150 Centre Avenue, Building A
Fort Collins, CO 80526-1891
Phone: (970) 295-5841
E-Mail: elsmith@fs.fed.us

Climate and Weather Data

National:

NATIONAL CLIMATE DATA CENTER

The National Climate Data Center provides online data and links to regional and state climate data centers:

National Climatic Data Center (NCDC)
Federal Building
151 Patton Avenue
Asheville NC 28801-5001
Phone: 828-271-4800
Fax: 828-271-4876

Available online: http://www.ncdc.noaa.gov/
(Last update: Jan. 30, 2002; accessed Feb. 5, 2002)

UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH

The University Corporation for Atmospheric Research (UCAR) is a consortium of universities dedicated to earth system research. It carries out its programs via the **National Center for Atmospheric Research** (NCAR) and the **UCAR Office of Programs** (UOP). These sites contain data, models, and numerous climate and geophysical links
.

University Corporation for Atmospheric Research
P.O. Box 3000
Boulder, Colorado 80307
Available online:
http://www.ucar.edu/ucar/index.html
(Last update: Jan. 29, 2002; accessed Feb. 5, 2002)

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Available online: http://www.ncar.ucar.edu/ncar/
(Accessed Feb. 5, 2002)

UCAR Office of Programs
Available online: http://www.uop.ucar.edu/uop/
(Accessed Feb. 5, 2002)

DSS RESEARCH DATA ARCHIVE

Available online: http://dss.ucar.edu/
(Last update: Jan. 30, 2002; accessed Feb. 5, 2002)

This site is affiliated with NCAR and UCAR.

Regional:

HIGH PLAINS REGIONAL CLIMATE CENTER

The High Plains Regional Climate Center includes CO, SD, and WY.

High Plains Regional Climate Center
University of Nebraska
830728 Chase Hall
Lincoln, NE 68583-0728
Phone: 402-472-6706
Fax: 402-472-6614

Available online: http://hpccsun.unl.edu/
(Accessed Feb. 5, 2002)

WESTERN REGIONAL CLIMATE CENTER

The Western Regional Climate Center includes AZ, CA, CO, ID, MT, NM, NV, OR, UT, WA, and WY. (CO and WY are affiliated with both the Western Regional Climate Center and with the High Plains Regional Climate Center.)

Western Regional Climate Center
Desert Research Institute
2215 Raggio Parkway
Reno, Nevada 89512
Phone: (775) 674-7010
Fax: (775) 674-7016

Available online: http://www.wrcc.dri.edu/
(Accessed Feb. 5, 2002)

By State:

ARIZONA

Office of Climatology
Arizona State University
P.O. Box 871508
Tempe, Arizona 85287-1508
Phone: (602) 965-6265
Fax: (602) 965-1473

CALIFORNIA

California Department of Water Resources
Division of Flood Management
Sacramento, California 94236-0001

COLORADO

Colorado Climate Center
Department of Atmospheric Science
Colorado State University
Fort Collins, Colorado 80523

Available online:
http://ulysses.atmos.colostate.edu/
(Accessed Feb. 5, 2002)

IDAHO

Idaho State Climate Services
Biological and Agricultural Engineering Dept.
University of Idaho
Moscow, Idaho 83844-0904

Available online: http://www.uidaho.edu/~climate/
(Accessed Feb. 5, 2002)

MONTANA

No current State climate data program
Contact WRCC for information.
(702) 677-3143

NEVADA

Dept. of Geography
College of Arts & Sciences
University of Nevada/Reno
Reno, Nevada 89557-0048

NEW MEXICO

New Mexico Climate Center
Department of Agronomy and Horticulture
Box 30001, Dept.3Q
New Mexico State University
Las Cruces, N M 88003-8003

Available online: http://weather.nmsu.edu/
(Last update: June. 26, 2002; accessed Feb. 5, 2002)

OREGON

Oregon Climate Service
Office of the State Climatologist
326 Strand Ag. Hall
Oregon State University
Corvallis, Oregon 97331-2209

Available online: http://ocs.oce.orst.edu/
(Accessed Feb. 5, 2002)

SOUTH DAKOTA

South Dakota Office of Climate and Weather
Agricultural Engineering Department
South Dakota State University
Brookings, SD 57006

Available online:http://www.abs.sdstate.edu/ae/weather/weather.htm (Accessed Feb. 5, 2002)

UTAH

Utah Climate Center
Utah State University
Logan, Utah 84322-4825

WASHINGTON

Atmospheric Sciences Dept.
University of Washington, AK-40
Seattle, Washington 98195

WYOMING

Wyoming Water Resources Center
University of Wyoming, UNN Station
Laramie, Wyoming 82071-3067

Available online:
http://www-wwrc.uwyo.edu/wrds/wsc/wsc.html
(Updated Sep. 27, 2001, accessed Feb. 5, 2002)

Wyoming State Climatologist and the Water Resources Data Systems (WRDS) for the State of Wyoming:

PO Box 3943
Laramie, WY 82071-3943
Phone: (307) 766-6651 Fax: (307) 766-3785

Available online:
http://www-wwrc.uwyo.edu/wrds/wrds.html
(Accessed Feb. 5, 2002)

Soils Data

National:

NATIONAL RESOURCE CONSERVATION SERVICE

Online soil survey data is available from:

Soil Survey Division
USDA-Natural Resources Conservation Service
Room 4250 South Building
14th & Independence Ave, SW
Washington, DC 20250
Phone: 202-720-1820
Fax: 202-720-4593

National Soil Survey Center available online:
http://www.statlab.iastate.edu/soils/nssc/
(Last updated Jan. 17, 2002, accessed Feb. 5, 2002)

NATURAL RESOURCE CONSERVATION SERVICE

The Natural Resource Conservation Service (NRCS) conducts soil surveys nationally. Links to regional offices, state soil scientists, and other sources of information are available from:

Natural Resources Conservation Service, (USDA)
Attn: Conservation Communications Staff
P.O. Box 2890
Washington, DC 20013

Available online: http://www.nrcs.usda.gov/
(Accessed Feb. 5, 2002)

Regional:

USDA FOREST SERVICE

Local Forest Service offices (regional offices and district offices) may have local soil surveys of National Forest lands. (NRCS surveys typically do not include Forest Service lands.)

NATIONAL RESOURCE CONSERVATION SERVICE

Pacific Northwest Soil Survey Region
USDA-NRCS
101 SW Main Street, Suite 1300
Portland, OR 97204-3221
Phone: 503-414-3003
Fax: 503-414-3277

Pacific Southwest Soil Survey Region
USDA-NRCS
430 G Street, #4164
Davis, CA 95616-4164
Phone: 530-792-5640
Fax: 530-792-5794

Northern Basin and Range Soil Survey Region
USDA-NRCS
5301 Longley Lane
Suite 201, Building F
Reno, NV 89511-1805
Phone: 775-784-5875
Fax: 775-784-5939

Northern Rocky Mountain Soil Survey Region
USDA-NRCS
Federal Building, Rm 443
10 East Babcock Street
Bozeman, MT 59715-4704
Phone: 406-587-6818
Fax: 406- 587-6761

Southern Rocky Mountain Soil Survey Region
USDA-NRCS
655 Parfet Street, Room E200C
Lakewood, CO 80215-5517
Phone: 303-236-2910
Fax: 303-236-2896

Northern Great Plains Soil Survey Region
USDA-NRCS
P.O. Box 1458
220 East Rosser Ave.
Bismarck, ND 58502-1458
Phone: 701-530-2025

Southwestern Basin, Range, Mountain and Plateau Soil Survey Region
USDA-NRCS
3003 N. Central
Suite 800
Phoenix, AZ 85012-2945
Phone: 602-280-8815
Fax: 602-280-8805

By State:

State NRCS web addresses are the same address as national site [above]) but with two-letter state abbreviation in the address between the “www.” and “nrcs” (e.g., for Colorado, the address would be:

http://www.co.nrcs.usda.gov/

State NRCS web sites often contain snowpack data.

ARIZONA

USDA, Natural Resources Conservation Service
18256 E. Williams Field Road, Suite 1
Higley, AZ 85236-6806
(602) 988-1078

COLORADO

State Conservationist
655 Parfet Street, Room E200C
Lakewood, CO 80215-5517
Phone: 303-236-2886
Fax: 303) 236-2896

CALIFORNIA

State Conservationist
430 G Street #4164
Davis, CA 95616-4164
Phone: 530-792-5600
Fax: 530)-792-5790

IDAHO

State Conservationist
9173 West Barnes Drive, Suite C
Boise, ID 83709-1574
Phone: 208-378-5700
Fax: 208-378-5735

MONTANA

State Conservationist
Federal Building, Room 443
10 East Babcock Street
Bozeman, MT 59715-4704
Phone: 406-587-6813
Fax: 406-587-6761

NEW MEXICO

State Conservationist
6200 Jefferson, NE
Suite 305
Albuquerque, NM 87109-3734
Phone: 505-761-4401
Fax: 505-761-4462

OREGON

State Conservationist
101 SW Main Street
Suite 1300
Portland, OR 97204-3221
Phone: 503-414-3201
Fax: 503-414-3277

SOUTH DAKOTA

State Conservationist
Federal Building, Room 203
200 4th Street, SW
Huron, SD 57350-2475
Phone: 605-352-1200
Fax: 605-352-1270

UTAH

(Mailing Address)
State Conservationist
P.O. Box 11350
Salt Lake City, UT 84147-0350

(Physical Address)
W.F. Bennett Federal Building
125 South State Street, Room 4402
Salt Lake City, UT 84138
Phone: 801-524-4550
Fax: 801-524-4403

WASHINGTON

State Conservationist
W. 316 Boone Avenue, Suite 450
Spokane, WA 99201-2348
Phone: 509-323-2900
Fax: 509-323-2909

WYOMING

State Conservationist
Federal Office Building, Room 3120
100 East B Street
Casper, WY 82601-1911
Phone: 307-261-6453
Fax: 307-261-6490

APPENDIX F: Version 1.1 updates

This appendix has 3 parts. Part 1 describes new uses for three *Beta.dat* file parameters (heretofore unused). Part 2 outlines code changes made June-December 2003, giving rise to this Version 1.1. Part 3 describes new output files.

Part 1: New *Beta.dat* parameters

B2(9): This parameter is now a "flag" controlling how leaf biomass and leaf area will be allocated to individual tree entities. Allocation of leaf prior to this change ignored crown information (it uses only bole volume). Via this flag, the user can re-allocate leaf tissue among entities, pro-rating the entire leaf pool among entities according to either crown volume, crown surface area, or the average of crown volume and crown surface area.

B2(9) value	meaning
1	volume method
-1	surface area method
-3	average of volume and surface area methods

Any other value results in BGC using the original un-adjusted leaf allocation.

B2(13): This parameter now controls how site occupancy is calculated. Code a "-1" to make site occupancy a function of root biomass. Any other value results in FVS-BGC using original leaf biomass (leaf area) method.

B2(21): This parameter is now the ratio of silhouette leaf area : projected leaf area. This term, combined B2(15) (ratio of all-sided to one-sided leaf area), is used to attenuate radiation through the canopy. This term should be a value between 0 and 1. Multiplied by B2(15), the value should represent a ratio of a silhouette LA : total (all-sided) leaf area. Code a "1" to run FVS-BGC without this adjustment.

Part 2

Outline of significant BGC code changes occurring since User Guide originally published (2002).

- LWP now a function of canopy layer height [6/25/03 BGROWN.F]. (Originally LWP was set equal to SWP. An intermediate version added a few tenths of (-MPa) to the SWP value to derive a LWP. Now, LWP=SWP + (-0.01 * Height)[14],where the coefficient 0.01 has units of MPa / m and height is in meters

[14] Note: the sign on the coefficient in these notes is negative corresponding to the fact that LWPs and SWPs are tensions, with units of -MPa. These values, in the code, are kept as positive values; hence one will not see the negative sign ("-") in the code.

- Created new routine: REDOLAI.F, called from BSTRUCTN.F. User now has option (via heretofore unused *beta.dat* parameter B2(9) to have the model re-adjust how it allocates leaf area to individual entities at time zero. Original code uses only bole volume (no crown information). New options allow user to tell model to allocate leaf area based on either: (a) crown volume, (b) crown surface area, or (c) the average of estimates (a) and (b). In any case, total cumulative (site-level) leaf area determined by the model to exist at time zero remains unchanged. [6/30-7/23/03 BSTRUCTN.F]
- Created new methodology for back-calculating the diameter growth of small trees (trees <2" dbh) from the volume increment. Prior to this change, the new diameter could be smaller than the earlier (pre-growth) diameter because of inconsistent assumptions about bole shape. New methodology is mathematically rigorous. Small trees must be at least 4.5' tall. Volume increments are unchanged. [7/14/03 BENTYLOAD, BENTYUPDATE, BUPDATE, BKILL].
- Make initialization of root biomass = 2* leaf (previously: root = leaf) [1/12/01 BINITIAL.F]
- User has option—via heretofore unused parameter B2(13)—of making site occupancy a function of root biomass instead of leaf biomass. [7/24/03 SITOCNF. Also BTRNOVR.F, BINITIAL.F, BSTNNDBGC.F,ENTITY.F]
- Amount of respiring stemwood now a function of crown ratio (CR). Previously 0.67. [7/28/03 BGROWN.F]
- Removed calculation of allocation ratios for entities that are not always on (e.g. grasses). Now grass allocation fractions are hard-coded to be 50% each to leaf and root. In order to re-implement original allocation logic, a flaw in allocation logic needs fixing: it assumes entities are always "on". [11/13/03 BALLOCA.F]
- Occupancy by trees now does not change as grasses shift from being "on" to "off" [11/18/03 BGROWN.F, SITOCN.F, SETLEAFN.F]
- Grasses, if on, bypass transpiration and psn if soil becomes too dry, but still perform maintenance respiration. [2/01 and 11/18/03. BGROWN.F]. (complex problem, see notes)
- Adjust information provided to and from penmon-monteith function so that transpiration calculation agrees with Forest-BGC documentation. (The result is that transpiration is slightly higher) [11/21/03 BGROWN.F]
- Lowered photon flux density by ratio of silhouette LA : projected LA for PSN, transpiration and conduction routines. Uses heretofore unused parameter B2(21) for entering the new parameter. [12/8 – 12/16/03 BGROWN.F]

Part 3:

New output files

DAYWATER.OUT

YEAR	Year
JD	Day
PPT	Precipitation reaching soil (mm)
MAX1	capacity of upper soil layer (m^3/ha))
MAX2	capacity of second water layer (m^3/ha)
SWC1	water content of upper layer (m^3/ha)
SWC2	water content of lower soil layer (m^3/ha)
RATIO1	proportion of upper layer capacity filled
RATIO2	proportion of upper layer capacity filled
WP1	water potential of upper layer (MPa * (-1))
WP2	water potential of lower layer (MPa * (-1))
OUT1	outflow (m^3/ha)
TR_GR	transpiration by grasses (m^3/ha)
TR_SM	transpiration by shrubs (m^3/ha)
TR_LG	transpiration by large trees (m^3/ha)
SITELAI	site LAI

VIGOR.OUT

YEAR	Year
TREE	Tree ID#
STEM_NPP	Stem NPP, g C / entity / year (all non-leaf, non-root production)
m^2_LA	m^2 of leaf area (projected-area basis) per entity
ENTY_VIGOR	grams of stemwood NPP / m^2 projected LA
TPH	trees per hectare
STEM_NPP	site total stem NPP (kg/ha/year)
m^2_LA	site total LA (projected, m^2)