The Simultaneous Heat and Water (SHAW) Model: User's Manual

Version 3.0.x

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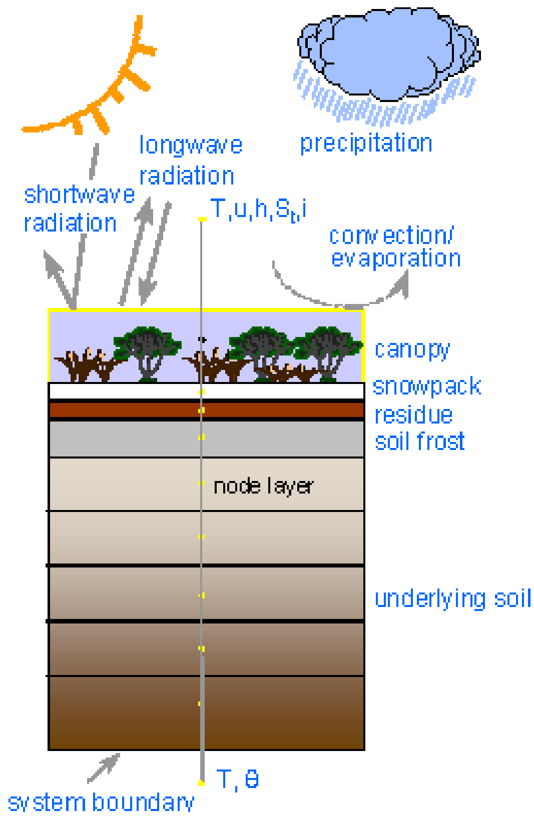

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Background and Overview

The Simultaneous Heat and Water (SHAW) model, originally developed to simulate soil freezing and thawing, simulates heat, water and solute transfer within a one-dimensional profile which includes the effects of plant cover, dead plant residue, and snow. Unique features of the model include: simultaneous solution of heat, water and solute fluxes; detailed provisions for soil freezing and thawing; and a sophisticated approach to simulating transpiration and water vapor transfer through a multi-species plant canopy. Information from the model can be used to assess management and climate effects on biological and hydrological processes, including seedling germination, plant establishment, insect populations, soil freezing, infiltration, runoff, and ground-water seepage.

Wintertime Processes

The SHAW model is one of the most detailed models available for snowmelt and soil freezing and thawing. The model has been shown to accurately simulate frost depth for a wide range of soil, climatic and surface conditions. It is capable of simulating complex wintertime phenomena of freezing effects on moisture and solute migration, solute effects on frost formation, and frozen soil related runoff. Transfer within the soil profile is solved concurrently with the surface energy and mass balance, which includes solar and long-wave radiation exchange, evaporation, and sensible and latent heat transfer.

Energy and mass transfer calculations for snow within the SHAW model are computed for a multi-layer snowpack. The energy balance of the snow includes solar and long-wave radiation exchange, sensible and latent heat transfer at the surface, and vapor transfer within the snowpack. Absorbed solar radiation, corrected for local slope, is based on measured incoming short-wave radiation, with albedo estimated from grain size, which in turn is estimated from snow density. Liquid water is routed through the snowpack using attenuation and lag coefficients, and the influence of metamorphic changes of compaction, settling and grain size on density and albedo are considered.

Evapotranspiration

The model is capable of simulating the effects of a multi-species plant canopy (including standing dead plant material) on heat and water transfer. Temporal variation in plant size, rooting depth, and leaf area index of each plant species is defined by the user. Provisions for a plant canopy in the SHAW model were made using detailed physics of heat and water transfer through the soil-plant-atmosphere continuum. Transpiration is linked mechanistically to soil water by flow through the roots and leaves. Within the plant, water flow is controlled mainly by changes in stomatal resistance, which is computed as a function of leaf water potential.

Input Requirements

Input to the SHAW model includes: initial conditions for snow, soil temperature and water content profiles; daily or hourly weather conditions (temperature, wind speed, humidity, precipitation and solar radiation); general site information; and parameters describing the vegetative cover, snow, residue and soil. General site information includes slope, aspect, latitude, and surface roughness parameters. Plant canopy parameters include height, leaf area index, biomass, leaf dimension, stomatal resistance parameters, and rooting depth. Residue or litter properties include residue loading, thickness of the residue layer, percent cover and albedo. Input soil parameters are bulk density, saturated conductivity, albedo, and coefficients for the soil water potential-water content relation.

User Interface

A user-interface called ShawGui has been developed for the SHAW model. ShawGui contains menus designed for ease of data entry. ShawGui will assist in creating the required input files for the SHAW model and run SHAW. ShawGui provides information about input parameters and performs range and error checking for input data.

ShawGui is a Java-based GUI (graphical user interface) that theoretically should be platform independent. Thus, rather than a Windows executable (*.exe) the file is “ShawGui.jar”. With the exception of actually running the SHAW model executable, it should be functional for creating the SHAW input files on a Unix or Linux system.

ShawGui is an update of the old user-interface “ModShell”. Input files for the ModShell interface can be read by ShawGui.

Getting Started

This section contains information on running the sample input files provided with the model, compiling the model, and some other useful information. The model can be downloaded from the SHAW ftp site (ftp://ftp.nwrc.ars.usda.gov/software/ShawModel/) or the SHAW web site (https://www.ars.usda.gov/pacific-west-area/boise-id/watershed-management-research/docs/shaw-model/) as a compressed zip file (SHAW30x.zip where “x” is the current sub-version of the model). Extract all of the files from the zip file to a directory of your choice.

Files included with distribution of the Simultaneous Heat and Water (SHAW) Model include: a "ReadMe.txt" file; an executable image of the SHAW model (SHAW30x.EXE where “x” is the current sub-version of the model); user-interface software (ShawGui.30x.jar); a sample input file for the user interface (TrialShawGui.gui); five trial input files for a sample SHAW run (Trial.*); and two directories named "Code" and "Output". The FORTRAN source file for the SHAW model is located in directory "Code"; output from the trial input files are located in the directory "Output". To simplify usage of the SHAW model, place both executable files (ShawGui.30x.jar and SHAW30x.exe) into a directory of your choice.

You can run the SHAW model with or without the user-interface software. The user interface has restrictions (such as no options for solute transport, no options for soil matric potential input in lieu of soil water content, no choice for the form of the soil moisture release curve, and no sub-surface lateral flow) that can be somewhat limiting. If this is the case, you can use the interface to build the input files, then alter them as needed.

ShawGui Sample Input

To run the ShawGui user interface, simply double-click on the ShawGui.jar file or type “ShawGui.jar” from the command line (don't type quotation marks, capitalization is not necessary). You will then be in the shell program, giving you a choice of menu options to input your data. Default parameters within ShawGui are such that it can immediately create SHAW input files and run the SHAW model from the SHAW Menu tab using the sample weather data file (Trial.30.wea). Thus, if the SHAW executable and Trial.30.wea are in the same directory as ShawGui.jar, it should be able create the other SHAW input files (the list of input/output files, the site file, the soil temperature file, and the soil moisture file) and run the SHAW model.

A sample data set (TrialShawGui.gui) for ShawGui is included with distribution of the model and may be used with the sample weather data file (Trial.30.wea). Open the TrialShawGui.gui file from the File menu tab. The path for the input and output files specified within the Control menu tab will likely need to be changed for the particular location of your trial input files. ShawGui will create input files for SHAW 3.0.x and will optionally run SHAW from the SHAW menu tab. Output files from the sample ShawGui input will be similar to the output files described in the SHAW 3.0 Sample Input subsection, but will have an extension of “guiOut” as specified in the Control menu tab. Additional output files may be specified from the Control menu tab.

SHAW 3.0 Sample Input

To run the sample input data set without the user-interface software, either double-click on the SHAW30x.exe file (where "x" is the current sub-version of the model) within Windows Explorer or execute "SHAW30x" from the command line prompt. The five sample input files for the model are:

Trial.30.inp	input file containing list of input/output files
Trial.30.wea	input file containing weather data
Trial.30.sit	input file containing site characteristics
Trial.moi	input file containing soil moisture profiles
Trial.tem	input file containing soil temperature profiles

Upon executing SHAW30, enter "Trial.30.inp" when prompted for the file containing the list of input/output files. (The full directory path will need to be entered if the Trial.30.inp file is not in the same directory as SHAW30x.exe.) The trial simulation will generate the following files:

Out.out	output file for general information
Temp.out	simulated soil temperature profiles
Moist.out	simulated soil water profiles
Energy.out	summary of simulated energy balance at the surface
Water.out	simulated water balance summary
Frost.out	simulated frost, thaw, and snow depths

For information on specifying other output files that may be generated or for information on putting together data sets for your own applications, you are referred to either the section "Input for SHAW 3.0" or the ShawGui user-interface. For information on the ShawGui user-interface, see the instructions entitled "SHAW 3.0.x User Interface".

Converting SHAW 2.x Input Files to SHAW 3.0

Although version 3.0 of the SHAW model will read input files from previous versions, a utility (Convert2Shaw30.exe) is provided to convert SHAW 2.3 input files to the format used by SHAW 3.0. This allows easier use of some of the expanded input/output options provided by version 3.0. Running the conversion utility is very similar to running the model. It will prompt the user for the list of input/output files; the directory path will need to be included if the file is not in the current directory when Convert2Shaw30.exe is started. The utility will create a new file for the list of input/output files, a new site file, and new plant growth files, if used. The utility will not convert the weather file from the mixed English/SI units. The IFLAGSI parameter will be set for the mixed English/SI units; if the input files were for a SHAW2.x-SI version of the model, the user will need to reset this parameter after running the utility.

Compiling the Model

If you wish to run the model on a system other than a Windows console application, you will probably need to compile the program on the particular system you plan to use. The computer code for the model uses standard Fortran 77 and should be transferrable to most any system.

Assistance

If you have questions concerning the model, encounter problems, or need additional information, please contact:

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SHAW 3.0.x User Interface

The SHAW model with user-interface enhancement ShawGui is composed of two distinct programs:

1. A Java-based graphical user interface (ShawGui.30x.jar where "x" is the current sub-version of the model), which contains menus designed for ease of data entry. This interface will create the required input files for the SHAW model.
2. The SHAW model itself (Shaw30x.exe), which requires input files created by either the shell program or by the user, along with a user supplied weather data file.

The interface can be very efficient for new users of the SHAW model to set up input files and run the SHAW model. The section of this manual entitled "Input for SHAW 3.0" describes how to create all the input files for the SHAW model without using the user-interface program.

Data Input

Menu options within the ShawGui interface include:

File:	allows you to recall input data from a previous simulation, save the current parameter settings, or reset all inputs to default settings.
Control:	specifies dates of simulation, location of input weather file, desired output files, and format of the weather file.
Site:	input general information for the site (latitude, slope, aspect etc.)
Vegetation:	input data for the plant canopy characteristics.
Soils:	input data for the soil characteristics.
Surface:	input data for residue, snow, and surface characteristics.
SHAW:	invokes the user interface to build all SHAW input files using the current data values, and, optionally, to execute the SHAW model simulation.

By progressing systematically through each of the other menu options prior to the "SHAW" option, the user will be prompted for all of the data necessary to build the input files (with the exception of the weather data file). At any time, and usually prior to invoking the "SHAW" option, the user can save the values input into the interface to a ShawGui parameter file, typically giving it an extension of *.gui.

The "SHAW" menu tab may be used to either simply create the input files for the SHAW model, or to run the SHAW model. In either case, this option will build and name the SHAW input data files as follows:

List of Input/Output files	:	*.inp
Moisture Profile Data	:	*.moi (created optionally)
Temperature Profile Data	:	*.tem (created optionally)
Site Characteristics	:	*.sit

where the filename (*) is the same as the ShawGui parameter file. The SHAW input files will be stored in the same directory as the ShawGui parameter file. If the ShawGui parameters have not been saved to a file, the default filename for the SHAW input files is TRIALgui.* and they will be placed in the same directory as the ShawGui executable.

Input files for initial temperature and moisture profiles and boundary conditions at the bottom of the soil profile may either be created by the user interface or supplied by the user, in which case the interface will prompt the user for the location of these input files. If desired, ShawGui will optionally extend the depth of the profile to 4 meters where soil temperature may be assumed constant. In this case, ShawGui will artificially create additional simulation depths down to 4 meters. Temperature at this bottom depth is estimated from the specified annual average air temperature. Initial water content to 4 meters is assumed equal to the deepest input water content.

The user must supply the weather data file in the format described in the "Input for SHAW 3.0" section of this manual. The name and format (daily or hourly) is specified by the user in the user interface under the "Control" menu tab.

Running the Model

Upon selecting the "SHAW" menu tab, the SHAW simulation will begin and the model will create data output files. File extensions and directory paths may be changed in the "Control" menu tab. The default names are as follows:

General output information	:	OUT.out
Predicted temperature	:	TEMP.out
Predicted moisture content	:	MOIST.out
Predicted soil water matric potential	:	MATRIC.out
Predicted soil liquid water content	:	LIQUID.out
Predicted plant canopy temperature profile	:	CANTMP.out
Predicted plant canopy humidity profile	:	CANTMP.out
Snow pack temperature profile	:	SNOWTMP.out
Summary of energy flux at surface	:	ENERGY.out
Water balance summary	:	WATER.out
Water flow between soil nodes	:	WFLOW.out
Frost depth and ice content profile	:	FROST.out

All the above file names and those for the input files are contained in the List of Input/Output files (e.g. Trial ShawGui.inp). The user can specify which files are desired and the frequency of output within each file in the "Control" menu tab of the user interface.

Input for SHAW 3.0

(Changes from SHAW 2.3 format are highlighted)

The SHAW model requires a minimum of five input files: 1) a file containing a list of input and output files; 2) a file containing initial soil moisture profile data; 3) a file containing initial temperature profile data; 4) a file containing weather data; and 5) a file containing general information and site characteristics. Input files specifying plant growth, changing plant parameters, and changing residue conditions are optional. The following sections give a description of the data required in each input file. All data files are read with free format, so data need only be separated with blanks and/or a comma.

List of Input/Output Files

The SHAW model will prompt you for the name of a file containing a list of the input and output files. This file must contain the following information:

Line A

IVERSION	Specifies version of the model for the input format. Valid versions include Shaw2.3 through Shaw3.0 and Shaw2.3-SI through Shaw2.8-SI. All "Shaw2.x" versions follow the input format of Shaw2.3; all "Shaw2.x-SI" versions assumes SI units for the weather file, i.e. wind speed in m/s and precipitation in mm instead of mph and inches in the standard versions of Shaw 2.x. Versions Shaw2.8 and Shaw2.8-SI use the input format for Shaw2.3, but allow for the extended output options of Shaw3.0, i.e. line C through C-19 in the list of input/output files. If line A of this file is missing and the file starts with line B, the model assumes that the input files follow the Shaw2.3 input format.

Line B

MTSTEP	Flag indicating time step for the weather data. (0 = hourly weather data; 1 = daily weather data; 2 = weather data is at same intervals as NHRPDT in Line D of the Site Characteristics file.
IFLAGSI	Flag indicating whether input weather files is in metric units or a mix of English and metric units. (0 = weather file has a mix of English and metric units; 1 = weather file is in metric units only).
INPH2O	Flag indicating whether input of soil water profiles for initial conditions (and lower boundary if applicable) are in terms of volumetric water content (INPH2O=0) or in matric potential (INPH2O=1).
MWATRXT	Flag indicating if a source/sink term for water extracted from soil layers will be input. MWATRXT=0 if no sink term is specified; MWATRXT=1 if a sink term is specified. (MWATRXT will be zero for nearly all cases.)

Line B-1	Name of input file containing site characteristics. The directory path must be included unless the file is in the current directory when the model is invoked. (Limit file path to 80 characters.)
Line B-2	Name of input file containing weather data. The directory path must be included unless the file is in the current directory when the model is invoked. (Limit file path to 80 characters.)

Line B-3 Name of input file containing moisture profile data. The directory path must be included unless the file is in the current directory when the model is invoked. (Limit file path to 80 characters.)

Line B-4 Name of input file containing temperature profile data. The directory path must be included unless the file is in the current directory when the model is invoked. (Limit file path to 80 characters)

Line B-5 Name of input file containing soil sink data for water extraction from soil layer. The directory path must be included unless the file is in the current directory when the model is invoked. (Omit this line if MATRXT in Line B is zero; limit file path to 80 characters.)

Line C

LVLOUT (1) Output frequency in hours for entire profile (canopy, snow, residue and soil conditions) in general output file. Value ranges between 0 (no profile output) and 24 (daily output). (However, a value of 1 will result in daily output if daily time steps are used; hourly time steps are required for hourly output.)

LVLOUT (3) Output frequency in hours for soil temperature profile output. (Range: 0 to 24.)

LVLOUT (4) Output frequency in hours for soil total water content profile. (Range: 0 to 24)

LVLOUT (5) Output frequency in hours for soil liquid water content profile. (Range: 0 to 24)

LVLOUT (6) Output frequency in hours for soil matric potential. (Range: 0 to 24)

LVLOUT (7) Flag indicating output for plant canopy air and leaf temperatures profiles. (0 = no output of canopy profile; positive values indicate the number of canopy nodes to output; Range: 0 to 10)

LVLOUT (8) Flag indicating output for plant canopy humidity profile. (0 = no output of canopy profile; values less than zero will output % relative humidity; positive values will output vapor pressure in kPa. The absolute value indicates the number of canopy nodes to output; Range: =-10 to +10)

LVLOUT (9) Output frequency in hours for snow temperature profile. (Range: 0 to 24)

LVLOUT (10) Output frequency in hours for surface energy balance. (Range: 0 to 24)

LVLOUT (11) Output frequency in hours for water balance summary. (Range: 0 to 24)

LVLOUT (12) Output frequency in hours for vertical water flow between soil layers. (Range: 0 to 24)

LVLOUT (13) Output frequency in hours for water extracted by plant roots. (Range: 0 to 24)

LVLOUT (14) Output frequency in hours for lateral sub-surface flow exiting soil profile. (Range: 0 to 24)

LVLOUT (15) Output frequency in hours for snow and frost depth. (Range: 0 to 24)

LVLOUT (16) Output frequency in hours for total salt concentration. (Range: 0 to 24)

LVLOUT (17) Output frequency in hours for soil solution concentration. (Range: 0 to 24)

LVLOUT (2) Flag indicating whether side-by-side comparison of simulated and measured moisture and temperature profiles is desired (0 if not, 1 if yes). (This option may be discontinued in the future.)

LVLOUT (18) Output flag for future development of the model. (Parameter is not currently used)

LVLOUT (19) Output flag for future development of the model. (Parameter is not currently used)

LVLOUT (20) Time step frequency for updating to screen the day and hour that the program has completed. (Range: ≥0; frequent updating to the screen may significantly increase run times; a value of zero indicates no updating to the screen.)

Line C-1 Name of output file for general output information and hourly or daily temperature, moisture and solute profile. (Limit file path to 80 characters.)

Line C-2	Name of output file for simulated temperature profiles. (Limit file path to 80 characters.)
Line C-3	Name of output file for simulated total water content profiles. (Limit to 80 characters.)
Line C-4	Name of output file for simulated liquid water content profiles. (Limit to 80 characters.)
Line C-5	Name of output file for simulated water potential profiles. (Limit to 80 characters.)
Line C-6	Name of output file for plant canopy temperature profiles. (Limit to 80 characters.)
Line C-7	Name of output file for plant canopy humidity profiles. (Limit to 80 characters.)
Line C-8	Name of output file for snow temperature profiles. (Limit to 80 characters.)
Line C-9	Name of output file for summary of energy flux at surface. (Limit to 80 characters.)
Line C-10	Name of output file for water balance summary. (Limit file path to 80 characters.)
Line C-11	Name of output file for water flow between soil layers. (Limit to 80 characters.)
Line C-12	Name of output file for water extracted by plant roots. (Limit file path to 80 characters.)
Line C-13	Name of output file for sub-surface lateral flow. (Limit file path to 80 characters.)
Line C-14	Name of output file for frost depth and ice content profiles. (Limit to 80 characters.)
Line C-15	Name of output file for total salt concentration profiles. (Limit to 80 characters.)
Line C-16	Name of output file for solute concentration of soil solution. (Limit to 80 characters.)
Line C-17	Name of output file for side-by-side comparison of simulated and measured moisture and temperature profiles at every time there is a moisture profile in the input moisture file. (Limit file path to 80 characters.)
Line C-18	Output file for potential future applications of the model. (Limit file path to 80 characters.)
Line C-19	Output file for potential future applications of the model. (Limit file path to 80 characters.)

(Each one of the lines C-1 through C-19 must be present, even if value of LVLOUT on line C indicates no output is desired.)

Moisture Profile Data File

The model requires at least two soil water profiles for the simulation site: one to initialize the profile for the day and hour on which simulation begins; and another on or after the last day of simulation to be used for interpolation of water content at the lower boundary between sampling times (depending on the value of IVLCBC, line J of the site characteristic file). The model will search through the data set for the profile corresponding to the day and hour on which simulation begins, so the file may contain moisture profile data for any number of sampling dates (ordered chronologically) before or after the simulation period. Any moisture profiles in the input file between the start and end of the simulation period will be used to print a comparison of measured and simulated moisture profiles (when LVLOUT(2) =1) and to interpolate water content at the lower boundary between sampling dates (when IVLCBC is set to 0). Each line within the file should contain the following data:

JDAY		Day of the year
JHR		Approximate hour at which samples were collected
JYR		Year during which samples were collected
VLCDT(I)	$\theta_l + (\rho_i/\rho_l)\theta_i$	Soil moisture for each soil node (I=1 to the number of soil nodes, NS). Soil moisture is given as the volumetric water (liquid + ice)
	or ψ	content (m^3/m^3) for INPH2O=0 (Line A of Input/Output file) or soil matric potential (m) for INPH2O=1.

Temperature Profile Data File

The discussion for the moisture profile data holds true for the temperature profile data, with the exception that simulated and measured temperature profile comparisons are output only at the moisture sampling times. Each line within the temperature profile data file should contain the following data:

JDAY		Day of the year
JHR		Hour at which temperatures were read
JYR		Year during which temperatures were read
TSDT(I)	T	Temperature data for each soil node (I=1 to the number of soil nodes, NS)

Weather Data File

Format of the weather data depends on the value MTSTEP in Line B of the Input/Output file. For MTSTEP=0, hourly weather data is expected and must be available for every hour during the simulation period. Hourly data must begin on or before hour 1 of the day to start simulation. The format for MTSTEP=2 is identical except data is expected at intervals equal to NHRPDT (line D of the Site Characteristics file) and must start on or before hour NHRPDT of the beginning day of simulation. Each line within the weather data must have the following data (for MTSTEP=0 or 2):

JD		Day of the year
JH		Hour of the day
JYR		Year
TA	T_a	Air temperature in degrees Celsius
WIND	u	Wind speed (m/s if IFLAGSI on Line B of input/output file equals 1 or if an "SI" version is specified on Line A; otherwise units are mph)
HUM	h	Relative humidity (%)
PRECIP	i	Precipitation (mm if IFLAGSI on Line B of input/output file equals 1 or if an "SI" version is specified on Line A; otherwise units are inches)
SNODEN	ρ_{sp}	Density of newly fallen snow if precipitation is snow (g/cm^3) (set to zero if density is unknown -- the model then will calculate a density based on air temperature)
SUNHOR	S_t	Total solar radiation measured on a horizontal surface (W/m^2)

For MTSTEP=1, daily weather data is expected starting on or before the beginning day of simulation. Each line of the daily weather data file must have the following information (for MTSTEP=1):

JD		Day of the year
JYR		Year
TMAX	T_a	Maximum daily air temperature in degrees Celsius
TMIN	T_a	Minimum daily air temperature in degrees Celsius
TDEW	T_d	Dew-point temperature in degrees Celsius
WIND	u	Average wind speed (m/s if IFLAGSI on Line B of input/output file equals 1 or if an "SI" version is specified on Line A; otherwise units are miles/day)
PRECIP	i	Daily precipitation (mm if IFLAGSI on Line B of input/output file equals 1 or if an "SI" version is specified on Line A; otherwise units are inches)
SOLAR	S_t	Average daily solar radiation measured on a horizontal surface (W/m^2)

Site Characteristics File

The input file containing site characteristics will vary depending on whether plants, snow or residue are present. The first five lines of the file (Lines A to E) are general input information for: the title of the run; simulation period; location and slope of the site; materials present and number of nodes; and aerodynamic roughness parameters. The next set of lines ("F-series" of lines) are needed only if plants or standing dead plant material are present for the simulation. This data is followed by: snow parameters ("G-series of lines); residue properties ("Line H") if surface residue is present; solute properties ("I-series" of lines) if solutes are to be considered; and soil properties ("J-series" of lines). Data required for each set of lines are listed below.

Line A

TITLE		Descriptive title (< 80 characters)

Line B

JSTART		Day of year on which simulation begins (may be 1 to 366)
HRSTAR		Hour on which simulation begins (may be 0 to 24)
YRSTAR		Year in which simulation begins
JEND		Day of year on which simulation ends
YREND		Year in which simulation ends

Line C

ALTDEG		Latitude of study site (degrees)
ALTMIN		Latitude of study site (minutes)
SLP	β	Slope of study site (%)
ASPEC	a_s	Aspect of slope (degrees clockwise from due north)
HRNOON	t_o	Time of solar noon. (Mid-point between sunrise and sunset; around 11.5 in the eastern part of the time zone, 12.5 in the western part of the time zone.)
ELEV		Elevation of site above sea level (m)

Line D

NPLANT		Number of different plant species to be simulated. (Include all standing dead plant material as one plant.)
NSP		Number of nodes in snowpack at beginning of simulation
NR		Number of desired residue nodes if residue does not change over the simulation ($0 \leq NR \leq 10$); set equal to 0 for no surface residue during the simulation; set to 1 if residue properties change, even if a residue does not exist at the beginning of the simulation.
NS		Number of soil nodes ($2 \leq NS \leq 50$)
NSALT		Number of solute types to be simulated ($NSALT \leq 10$)
TOLER		Error tolerance for convergence criteria (^{o}C for energy balance and fraction of change in matric potential or vapor density for water; suggested value: .001 to .01)
NHRPDT		Number of hours per time step (must be evenly divisible into 24 hours, i.e.: 1,2,3,4,6,8,12, or 24 hours)
LEVEL(1)		Debugging output level: 0 = no debugging output is desired; 1 = profile summary every iteration; and 2 = full debugging mode (fluxes, Newton-Raphson matrix, etc.)
LEVEL(2)		Day on which to stop debugging at LEVEL(1) and to start at LEVEL(4)
LEVEL(3)		Hour at which to stop debugging at LEVEL(1) and to start at LEVEL(4)
LEVEL(4)		Secondary level of output (values identical to LEVEL(1))
LEVEL(5)		Day on which to resume debugging at LEVEL(1)
LEVEL(6)		Hour at which to resume debugging at LEVEL(1)

Line E

ZMCM	z_m	Wind-profile surface-roughness parameter for momentum transfer (cm) for the residue or soil surface. (Typical value is 0.1 cm for a very smooth surface to 10 cm for a very rough surface.)
HEIGHT		Measurement height for air temperature, windspeed and humidity (m). Typical value is 2 or 3m, but it MUST be greater than any anticipated plant canopy height.
PONDMX		Maximum depth of ponding for rainfall or snowmelt (cm)

Line F ("F-series of lines not included if NPLANT=0)

MCANFLG		Flag controlling options for input of plant growth curves and node spacing. (0 = no plant growth, i.e. leaf area index and plant height are constant for simulation, and model will determine node spacing within the canopy; 1 = input files for plant growth are specified for each plant and model will determine node spacing within the canopy; 2 = no plant growth and allows user to input spacing and parameters of plant canopy layers; 3 = input files for plant growth are specified for each plant and the user can specify desired heights above ground surface for canopy nodes.) Option 3 is intended for subsequent comparison with measurements of temperature and humidity at specified heights within the canopy.
ISTOMATE		Flag to select option for computing stomatal resistance; 1 = default computation of stomatal resistance as a function of leaf water potential; 2 = option for additional controls on stomatal conductance using Stewart-Jarvis type functions for solar radiation, air temperature and vapor pressure deficit.
CANMA	a_c	Coefficient for water potential of dead plant material: $\psi = a_c w_c^{-b_c}$ where w_c is mass basis water content within canopy. (Suggested value: - 53.72 m)
CANMB	b_c	Exponent for water potential of dead plant material. (Suggested value: 1.32)

WCANDT	w	Initial water content of standing dead plant material (kg/kg). (If less than or equal to zero, the model will estimate initial value based on atmospheric humidity.)

<u>Lines F-1 to F1-NPLANT</u>

ITYPE(J)		Parameter specifying plant type for plant species j: 1 = transpiring plant; 0 = dead plant material. (Only 1 dead plant is allowed.)
PINTRCP(J)		Maximum amount of precipitation that can be intercepted and stored on plant species j per unit of leaf area index. This value was set to 1 mm in SHAW 2.x; suggested value: 0 to 1 mm.
XANGLE(J)		Parameter specifying "x" parameter for leaf angle orientation of plant species j: 0 = vertical leaf angle orientation; 1 = random leaf orientation; values approaching 5 will simulate a horizontal leaf angle orientation.
CANALB(J)	α_c	Albedo of plant species j (<1.0)
TCCRIT(J)	T_c	Temperature above which plant species j will transpire (°C). (Applicable only if ITYPE(J) > 0.)
RSTOM0(J)	r_{so}	Stomatal resistance of plant species j with no water stress (s/m). Typical value: 100 s/m.
RSTEXP(J)	n	Empirical exponent relating actual stomatal resistance to leaf potential: $r_s = r_{so}[1 + (\psi_P/\psi_c)^n]$. Typical value: 5
PLEAF0(J)	ψ_c	Critical leaf water potential for plant species j at which stomatal resistance is twice its minimum value (m). Typical value: -100 m to -300 m.
RLEAF0(J)	r_p	Resistance of leaves for plant species j ($m^3\ s\ kg^{-1}$). Typical value: $1x10^5\ m^3 s\ kg^{-1}$.
RROOT0(J)	r_r	Resistance of roots for plant species j ($m^3\ s\ kg^{-1}$). Typical value: $2x10^5\ m^3\ s\ kg^{-1}$.

Approximately 2/3 of the total resistance to water flow through the plant is encountered in the roots while 1/3 is encountered in the leaves. Typical values of total plant resistance for some common plants are given below.

Plant	Total resistance ($m^3\ s\ kg^{-1}$)
alfalfa	79,000
aspen	500,000
barley	650,000
clover	135,000
corn	123,000
creosote bush	2,940,000

Plant	Total resistance ($m^3\ s\ kg^{-1}$)
Douglas fir	99,000
fescue (grass)	115,000
rice	59,000 to 379,000
sagebrush	2,370,000
soybean	32,000 to 463,000
wheat	32,000 to 463,000

<u>Lines Fa-1 to Fa-NPLANT</u> ("Fa-series" of lines applicable only if ISTOMATE=2)

STOMATE(J,1)	K_{St}	Parameter to control influence of solar radiation on stomatal conductance of plant species j ($W\ m^{-2}$). $f(S_{t,i}) = S_{t,i}(1000 + K_{St})/(1000(S_{t,i} + K_{St}))$ where $S_{t,i}$ is the total solar radiation incident on canopy layer i. ($K_{St} \geq 0$; set to 0 for no influence of solar radiation on stomatal conductance.)
STOMATE(J,2)	T_L	Lower limit for transpiration; no stomatal conductance below this temperature (C). (Set to -999 for essentially no influence of temperature on stomatal conductance, except that there will be no transpiration below TCCRIT(J) in Line F-j)
STOMATE(J,3)	T_H	Upper limit for transpiration; no stomatal conductance above this temperature (C). (Set to +999 for essentially no influence of temperature on stomatal conductance.)

STOMATE(J,4)	T_{Opt}	Optimum temperature for transpiration (C); no reduction in stomatal conductance at this temperature
STOMATE(J,5)	K_{VPD}	Maximum reduction in stomatal conductance due to vapor pressure deficit. ($0< K_{VPD} \leq 1.0$; set to 1.0 for no influence of vapor pressure deficit on stomatal conductance.)
STOMATE(J,6)	r	Coefficient for stomatal conductance due to vapor pressure deficit. $f(VPD) = K_{VPD} + [1 - K_{VPD}]r^{VPD}$ where VPD is the vapor pressure deficit in kPa. ($0<r\leq1.0$)
STOMATE(J,7)	$K_{\theta 1}$	Control of stomatal conductance for water content is currently not available because it is implicitly controlled through leaf water potential; set to 0.0.
STOMATE(J,8)	$K_{\theta 2}$	Control of stomatal conductance for water content is currently not available; set to 0.0.

Lines F0-1 to F0-NPLANT ("F0-series" of lines applicable only if MCANFLG=0)

PLTHGT(J)		Height of plant species *j* (m)
DCHAR(J)		Characteristic dimension (i.e. width) of leaves of plant species *j* (cm)
CLUMPNG(J)	Ω	Plant clumping parameter for radiation transfer. (1 = uniform vegetation; $0< \Omega<1$ indicates varying degrees of clumping; a value of zero will practically eliminate radiation interception by plants.)
PLTWGT(J)		Dry biomass of plant species *j* (kg/m^2)
PLTLAI(J)		Leaf area index of plant species *j*
ROOTDP(J)		Effective rooting depth of plant *j* (m); value is not used in case of standing dead material (ITYPE = 0), but a value must still be present.

Line F1-1 to F1-NPLANT ("F1-series" of lines applicable only if MCANFLG=1)

IFILE(J)	Input file for growth or changing condition of plant species *j*

Line F2 ("F2-series" of lines applicable only if MCANFLG=2)

NC	Number of desired canopy nodes ($NC \leq 10$)

Lines F2a-1 to F2a-NC ("F2-series" of lines applicable only if MCANFLG=2)

ZC(I)		Distance of node *i* from top of canopy; ZC(1) must be 0.0 (m)
DCHAR(J)	d_c	Characteristic dimension of leaves of plant species *j* (cm). (For a given plant species, the value of this parameter will be the same for all canopy layers.)
CLUMPNG(J)	Ω	Plant clumping parameter for radiation transfer of plant species *j*. (1 = uniform vegetation; $0< \Omega<1$ indicates various degrees of clumping.)
DRYCAN (J,I)		Dry biomass of plant *j* in canopy layer *i* (kg/m^2)
CANLAI(J,I)	L	Leaf area index of plant *j* in canopy layer *i*

Repeat [DCHAR(J), CLUMPNG(J), DRYCAN(J,I), CANLAI(J,I)] on each line for each plant species, i.e., J = 1 to NPLANT

Lines F2a-NC+1 (Include only if MCANFLG=2)

ZC(NC+1)	Distance from top of canopy to residue or soil surface (m)

Line F2b to F2b-NPLANT ("F2b-series" of lines applicable only if MCANFLG=2)

ROOTDN(J,I) I=1 to NS — Fraction of the total roots for plant species J in soil layer I. Each line will have a value for each soil layer; one line for each plant species. A line is needed for the standing dead material, but values are not used, therefore a line of zeroes will suffice.

Line F3-1 to F1-NPLANT ("F3-series" of lines applicable only if MCANFLG=3)

IFILE(J) — Input file for growth or changing condition of plant species *j*

Line F3a ("F3a-series" of lines applicable only if MCANFLG=3)

NC — Number of desired canopy nodes (NC ≤ 10). Excess nodes above maximum canopy height are ok, but will not be used. For dense canopies, the user should distribute extra nodes within the canopy space so that each layer does greatly exceed an LAI of 0.5. (You may want to adjust the values of LVLOUT(7) and LVLOUT(8) based on the value of NC.)

Line F3b ("F3b" of line applicable only if MCANFLG=3)

HEIGHTS(I), I=1,NC — Height from ground surface for desired placement of canopy nodes. HEIGHT(1) is nearest the ground (but > 0) and HEIGHT(NC) should be ≥ the maximum canopy height during the simulation. The model will use as many nodes as necessary to accommodate the canopy height. Actual placement of the bottom node by the model may vary depending on snow depth; actual placement of the highest node used by the model at any given time will equal the actual height of the canopy. Extra nodes above the actual height of the canopy will not be used. (Number of heights listed must equal NC.)

Line G

ISNOTMP		Flag to indicate whether the threshold temperature for snow (SNOTMP) is based on air temperature or wet bulb temperature. 1= air temperature; 2 = wet bulb temperature.
SNOTMP		Maximum temperature at which precipitation is snow (unless density of snow is supplied in weather data file) (°C)
ZMSPCM	z_m	Wind-profile roughness parameter for momentum transfer with snowcover (cm); suggested value for smooth snow surface: 0.15 cm
ISNOPARM		Flag allowing input of selected snow parameters. (Option is not currently available; set to 0).

Lines G1-1 to G1-NSP (not included if NSP = 0)

DZSP(I)		Thickness of snow layer *i* at beginning of simulation (m)
TSPDT(I)		Temperature of snow layer *i* at beginning of simulation (°C)
DLWDT(I)		Depth of liquid water stored in snow layer *i* (m)
RHOSP(I)	ρ_{sp}	Bulk density of ice fraction in layer *i* at beginning of simulation (kg/m^3)

Line H (Omit if NR=0)

NRCHANG		Flag indicating whether the residue changes over time are input to the model (0 = residue parameters are assumed constant; 1 = changes in residue cover are input to the model.)
GMCDT	w_r	Initial gravimetric water content of residue at start of simulation (kg/kg). (If input

is less than or equal to zero, the model will estimate initial value based on soil matric potential.)

Line H1 (Omit if NR=0 or if NRCHANG=1)

ZRTHIK		Thickness or depth of residue layer (cm)
RLOAD	W	Dry weight of residue on surface (kg/ha)
COVER		Fraction of surface covered by residue
ALBRES	α_r	Albedo of residue; suggested value: 0.25
RESCOF	$1/K_r$	Resistance to vapor transfer (s/m) between residue elements and air voids in residue layer *i*; suggested value 1000-50,000 s/m. (If moisture content of residue layer is not a concern in the simulation, larger resistance values will improve convergence with little effect on the overall simulation.)
RESTKB	k_{rb}	Parameter for the influence of windspeed at surface of residue layer on the transfer of heat and vapor through the residue layer. (Suggested values: 4.0 for wheat residue; 8.5 for larger residue elements such as corn stalks lying horizontal.)

Line H2 (Omit if NR=0 or if NRCHANG=0)

IFILE		Input file for changing residue conditions

Line I-1 ("I-series" of lines repeated for each type of solute; omit if NSALT = 0)

SLTDIF(I)	D_o	Diffusion coefficient for solute *i* at 0°C (m^2/s)
HALFLIF		Half-life of solute *i* in the soil environment (days). (Enter zero if the solute does not degrade over time.

Line I-2

SALTKQ(I,J)	K_d	Partitioning coefficient between soil matrix and soil solution (kg/kg) for solute *i* in soil layer *j* (one value for each soil layer). Values depend on solute and soil type and range from near 0 for chloride, which is not bound to soil particles to about 60 for potassium which is tightly bound to soil particles

Line I-3

SALTDT(I,J)	S	Moles of solute *i* per kg of soil in layer *j* (one value for each soil layer)

Line J1

IVLCBC		Flag indicating boundary condition for water flow at bottom of profile: 0 = specified water content; 1 = unit gradient assumed for water flow at lower boundary. (A no-flow lower boundary may be specified by setting saturated hydraulic conductivity, SATCON, at the lower boundary to zero.)
ITMPBC		Flag indicating boundary condition for temperature at bottom of profile: 0 = model will track temperature for bottom soil node in Temperature Profile Data File; 1 = boundary temperature estimated by model based soil temperature response above the lower boundary and assumed constant temperature (TSAVG) below the boundary; 2 = no heat flux at the lower boundary (usually used for laboratory column experiments). (If lower temperatures are not available, most accurate simulations may be obtained by extending profile to a depth where temperature can be assumed constant and approximated by mean annual air temperature.)
ALBDRY	α_d	Albedo of dry soil (<1.0). Typical values: 0.15 to 0.30.
ALBEXP	a_α	Exponent for calculating albedo of moist soil: $\alpha = \alpha_d \exp(-a_\alpha \theta_l)$. Typical values:

0 to 3.5.

IWRC		Flag to select equation for the water release curve: 1 = Campbell equation; 2 = Brooks-Corey equation; 3 = van Genuchten equation.
IPHANTOM		Flag to allow model to insert additional soil nodes if the layering is deemed too sparse. (Option is currently not available; set to 0).

Lines J2 (Omit if ITMPBC does not equal 1)

TSAVG		Average annual soil temperature (C). This may be approximated by the average annual air temperature and is used to estimate soil temperature at the lower boundary.

Lines J3-1 to J3-NS when IWRC = 1 (Campbell equation)

ZS(I)		Depth in meters of soil node *i;* ZS(1) must be 0.0 (m)
SAND(I)		Percent by weight of the sand, silt and clay in soil layer *i* that is sand
SILT(I)		Percent by weight of the sand, silt and clay in soil layer *i* that is silt
CLAY(I)		Percent by weight of the sand, silt and clay in soil layer *i* that is clay
ROCK(I)		Percent by weight of soil material in layer *i* that is rock or gravel
OM(I)		Percent by weight of soil material in layer *i* that is organic matter
RHOB(I)	ρ_b	Bulk density in kg/m^3 of soil layer *i* (kg/m^3)
SATCON	K_s	Saturated conductivity for soil layer *i* (cm/hr)
SATKL	$K_{s\text{-}lat}$	Lateral saturated conductivity for lateral sub-surface flow exitin soil layer *i* (cm/hr). When soil layer is saturated, lateral flow exiting layer is computed based slope and $K_{s\text{-}lat}$
SOILWRC(I,1)	ψ_e	Air-entry potential in meters for soil layer *i* (m)
SOILWRC(I,2)	θ_s	Saturated volumetric moisture content (if greater than calculated porosity, 1_s is set equal to porosity)
SOILWRC(I,3)	b	Cambell's pore-size distribution index for soil layer *i*; $\psi = \psi_e [\theta / \theta_s]^{-b}$
ASALT(I)	τ	Molecular diffusion parameter for solutes in soil layer *i*; not required if NSALT=0
DISPER(I)	κ	Parameter for hydrodynamic dispersion coefficient (m); not required if NSALT=0

Lines J3-1 to J3-NS when IWRC = 2 (Brooks-Corey equation)

ZS(I)		Depth in meters of soil node *i;* ZS(1) must be 0.0 (m)
SAND(I)		Percent by weight of the sand, silt and clay in soil layer *i* that is sand
SILT(I)		Percent by weight of the sand, silt and clay in soil layer *i* that is silt
CLAY(I)		Percent by weight of the sand, silt and clay in soil layer *i* that is clay
ROCK(I)		Percent by weight of soil material in layer *i* that is rock or gravel
OM(I)		Percent by weight of soil material in layer *i* that is organic matter
RHOB(I)	ρ_b	Bulk density in kg/m^3 of soil layer *i* (kg/m^3)
SATCON	K_s	Saturated conductivity for soil layer *i* (cm/hr)
SATKL	$K_{s\text{-}lat}$	Lateral saturated conductivity for sub-surface flow in soil layer *i* (cm/hr). When soil layer is saturated, lateral flow exiting layer is computed based slope and $K_{s\text{-}lat}$
SOILWRC(I,1)	ψ_e	Air-entry potential in meters for soil layer *i* (m)
SOILWRC(I,2)	θ_s	Saturated volumetric moisture content (if greater than calculated porosity, 1_s is set equal to porosity)
SOILWRC(I,3)	λ	Brooks-Corey pore-size distribution parameter
SOILWRC(I,4)	θ_r	Residual volumetric moisture content
SOILWRC(I,5)	l	Pore-connectivity parameter; assumed to be 2.0 in the original Brooks and

		Corey model; $K = K_s(\psi/\psi_e)^{-(\lambda(l+2)+2)}$
ASALT(I)	τ	Molecular diffusion parameter for solutes in soil layer *i*; not required if NSALT=0
DISPER(I)	κ	Parameter for hydrodynamic dispersion coefficient (m); not required if NSALT=0

Lines J3-1 to J3-NS when IWRC = 3 (Van Genuchten equation)

ZS(I)		Depth in meters of soil node *i;* ZS(1) must be 0.0 (m)
SAND(I)		Percent by weight of the sand, silt and clay in soil layer *i* that is sand
SILT(I)		Percent by weight of the sand, silt and clay in soil layer *i* that is silt
CLAY(I)		Percent by weight of the sand, silt and clay in soil layer *i* that is clay
ROCK(I)		Percent by weight of soil material in layer *i* that is rock or gravel
OM(I)		Percent by weight of soil material in layer *i* that is organic matter
RHOB(I)	ρ_b	Bulk density in kg/m^3 of soil layer *i* (kg/m^3)
SATCON	K_s	Saturated conductivity for soil layer *i* (cm/hr)
SATKL	$K_{s\text{-}lat}$	Lateral saturated conductivity for sub-surface flow in soil layer *i* (cm/hr). When soil layer is saturated, lateral flow exiting layer is computed based slope and $K_{s\text{-}lat}$
SOILWRC(I,1)	ψ_e	Air-entry potential in meters for soil layer *i* ; set ψ_e equal to zero for Van Genuchten equation (m)
SOILWRC(I,2)	θ_s	Saturated volumetric moisture content (if greater than calculated porosity, 1_s is set equal to porosity)
SOILWRC(I,3)	*n*	Empirical exponent in Van Genuchten equation
SOILWRC(I,4)	θ_r	Residual volumetric moisture content
SOILWRC(I,5)	*l*	Pore-connectivity parameter in the Van Genuchten equation; estimated to be 0.5 for an average of many soils (Mualem, 1976).
SOILWRC(I,6)	α	Empirical coefficient in Van Genuchten equation (m^{-1})
ASALT(I)	τ	Molecular diffusion parameter for solutes in soil layer *i*; not required if NSALT=0
DISPER(I)	κ	Parameter for hydrodynamic dispersion coefficient (m); not required if NSALT=0

Plant Growth Files (Optional)

Plant growth files are required only if MCANFLG=1 or 3 (Line F of the Site Characteristics File). One file is required for each plant type, including any standing dead plant material. The name of each file is specified in Lines F3 of the Site Characteristics File. Each line of the plant growth file will contain the plant characteristics for a given day. The model will interpolate values between given days. If a plant is not present for any part of the simulation, a value of zero may given for the leaf area index and plant height. Unlike the temperature and moisture input files, data need not be present for the day on which the simulation begins; the model will interpolate between days to obtain initial conditions at the start of the simulation. Values given in the plant growth files are not adjusted for plant stress or growth-limiting conditions. Each line of the file should contain the following data:

JDAY		Day of year
JYR		Year for observed plant characteristics
PLTHGT(J)		Height of plant species *j* on day JDAY (m)
DCHAR(J)		Characteristic dimension of leaves of plant species *j* on day JDAY (cm)
CLUMPNG(J)	Ω	Plant clumping parameter for radiation transfer. (1 = uniform vegetation; 0< Ω<1 indicates various degrees of clumping.)
PLTWGT(J)		Dry biomass of plant species j on day JDAY (kg/m2)
PLTLAI(J)		Leaf area index of plant species *j* on day JDAY

ROOTDP(J)		Effective rooting depth of plant *j* on day JDAY (m)

Surface Residue File (Optional)

A residue parameter file is required only if NRCHANG=1 (Line H of the Site Characteristics File). The file describes the change in residue cover over time. The name of the file is specified in Lines H-2 of the Site Characteristics File. Each line of the surface residue file will contain the residue characteristics for a given day. The model will interpolate values between given days. If a residue is not present for any part of the simulation, a value of zero may given for the thickess of the residue layer. Unlike the temperature and moisture input files, data need not be present for the day on which the simulation begins; the model will interpolate between days to obtain initial conditions at the start of the simulation. Each line of the file should contain the following data:

JDAY		Day of year
JYR		Year for observed plant characteristics
ZRTHIK		Thickness or depth of residue layer on day JDAY (cm)
RLOAD	W	Dry weight of residue on surface on day JDAY (kg/ha)
COVER		Fraction of surface covered by residue on day JDAY
ALBRES	α_r	Albedo of residue on day JDAY; suggested value: 0.25
RESCOF	$1/K_r$	Resistance to vapor transfer on day JDAY (s/m) between residue elements and air voids in residue layer *i*; suggested value 1000-50,000 s/m. (If moisture content of residue layer is not a concern in the simulation, larger resistance values will improve convergence with little effect on the overall simulation.)
RESTKB	k_{rb}	Parameter for the influence of windspeed at surface of residue layer on the transfer of heat and vapor through the residue layer. (Suggested values: 4.0 for wheat residue; 8.5 for larger residue elements such as corn.)

Soil Source/Sink File (Optional)

The soil source/sink file is used only if MWATRXT (Line A in the List of Input/Output Files) is set to 1 and is not necessary for most model applications. The purpose of the file is to give the user the option to artificially extract (positive) or introduce (negative) water within the soil profile. Examples of where this might be useful is for: sub-surface irrigation; water seeping into the soil profile; direct input of the output of water extracted by plant roots from a previous run (Line C-12 in the List of Input/Output files; direct input of the output of lateral sub-surface flow from a previous run (Line C-13 in the List of Input/Output files). Water extraction from a layer will be limited within the model by the water available within that layer. Introduction of water into the profile is not limited by the model; thus, the user is cautioned that excessive water introduction may cause numerical problems. Input values for each soil layer are assumed to be the cumulative depth of water extracted between observations. Water extracted for each time step between observations will be computed and will be assumed constant. Unlike the temperature and moisture input files, data need not be present for the day on which the simulation begins; there needs to be at least one observation on or before the beginning date of simulation and at least one on or after the ending date.

JDAY	Day of the year
JHR	Hour at which temperatures were read
JYR	Year during which temperatures were read
SOILXT(I)	Cumulative depth of water (m) extracted from for each soil layer (I=1 to the number of soil nodes, NS) between current day and hour (JDAY and JHR) and the day and hour on the previous line of data. (I=1 to the number of soil nodes, NS,

i.e. one value for each soil node.)

Sample Input Files

List of Input/Output Files

```
Shaw 3.0
0 0 0 0
TRIAL.30.SIT
TRIAL.30.WEA
TRIAL.MOI
TRIAL.TEM
  24  24  24  24  0  0  0  0  24  24  0  0  0  6  0  0  0  0  24
out.out
temp.out
moist.out
liquid.out
matric.out
cantmp.out
canhum.out
snowtmp.out
energy.out
water.out
wflow.out
rootxt.out
lateral.out
frost.out
salts.out
solute.out
```

Moisture Profile Data

```
 308  18  86 0.352 0.352 0.337 0.354 0.280 0.290 0.293 0.316 0.364 0.335 0.365
 323  12  86 0.385 0.385 0.366 0.402 0.296 0.317 0.417 0.440 0.503 0.443 0.425
 338  12  86 0.374 0.374 0.365 0.381 0.270 0.290 0.297 0.295 0.336 0.334 0.343
 349  12  86 0.465 0.465 0.353 0.367 0.295 0.310 0.325 0.352 0.433 0.427 0.437
 365  12  86 0.417 0.417 0.350 0.375 0.294 0.311 0.317 0.336 0.376 0.354 0.377
  14  12  87 0.419 0.419 0.335 0.361 0.293 0.301 0.311 0.330 0.372 0.345 0.372
  28  12  87 0.469 0.469 0.364 0.398 0.307 0.318 0.318 0.333 0.372 0.345 0.373
  43  12  87 0.351 0.351 0.357 0.394 0.302 0.324 0.323 0.339 0.381 0.361 0.392
  57  12  87 0.364 0.364 0.352 0.391 0.303 0.313 0.321 0.338 0.375 0.356 0.378
```

Temperature Data

```
 308  18  86   5.7    6.4    7.1    7.8    8.6    9.5   10.3   10.7   11.3   11.8   12.2
 308  21  86   5.3    6.3    7.1 99999    8.6    9.4   10.3   10.7   11.3   11.8   12.2
 309   0  86   5.3    6.2    7.0 99999    8.5    9.4   10.2   10.7   11.3   11.8   12.1
 338   0  86   1.1    1.9    2.8 99999    4.4    5.4    6.2    6.7    7.5    8.4    9.4
 338   6  86   0.5    1.7    2.8 99999    4.5    5.4    6.2    6.7    7.4    8.4    9.4
 338   9  86   0.4    1.5    2.6 99999    4.3    5.3    6.2    6.7    7.4    8.4    9.4
 338  12  86   2.7    2.1    2.8    3.7    4.6    5.4    6.2    6.7    7.5    8.4    9.4
 339  18  86   1.9    2.3    3.0 99999    4.3    5.2    6.0    6.5    7.3    8.3    9.3
 339  24  86   1.9    2.2    3.0 99999    4.3    5.2    6.0    6.4    7.3    8.3    9.3
 340  12  86   2.1    2.3    3.0 99999    4.4    5.1    5.9    6.4    7.3    8.2    9.2
 353   6  86  -0.3    0.3    1.2 99999    2.5    3.5    4.4    5.0    5.9    7.0    8.2
 353  12  86   0.1    0.4    1.2 99999    2.6    3.5    4.4    5.0    5.9    7.0    8.2
 353  18  86   0.1    0.4    1.2 99999    2.5    3.5    4.4    4.9    5.9    7.0    8.2
 354   0  86  -0.5    0.4    1.1 99999    2.6    3.5    4.3    4.9    5.8    7.0    8.1
```

Hourly Weather Data
Hourly weather format is used when MTSTEP (Line A in List of Input/Output Files) is set to 0 or 2.

```
 311   0  86    1.4   3.82   98.7   0.0   0       0.0
 311   1  86    1.1   4.91  100.5   0.0   0       0.0
 311   2  86    0.7   4.59  100.7   0.0   0       0.0
 311   3  86    0.4   4.81  100.9   0.0   0       0.0
 311   4  86    0.3   5.66  100.7   0.0   0       0.0
 311   5  86    0.2   6.35  100.1   0.0   0       0.0
                      .
                      .
                      .
 338   0  86   -0.8   1.29   99.9   0.0   0      -0.2
 338   1  86   -0.6   0.93   99.9   0.0   0      -0.2
 338   2  86   -0.5   0.31   99.4   0.0   0      -0.2
 338   3  86   -0.3   0.81   98.9   0.0   0      -0.2
 338   4  86   -0.7   1.75   97.2   0.0   0      -0.1
 338   5  86   -1.0   2.34   97.1   0.0   0      -0.1
 338   6  86   -1.4   1.51   98.1   0.0   0      -0.1
 338   7  86   -1.3   1.26   98.7   0.0   0      -0.1
 338   8  86   -1.1   1.37   97.9   0.0   0       8.8
 338   9  86   -1.0   1.02   96.5   0.0   0      55.6
 338  10  86   -0.4   0.65   96.3   0.0   0     123.4
 338  11  86    0.1   1.19   95.7   0.0   0     157.7
 338  12  86    0.7   0.72   95.9   0.0   0     162.2
 338  13  86    1.0   0.82   93.1   0.0   0     160.4
 338  14  86    1.2   1.66   90.4   0.0   0     131.4
 338  15  86    1.5   1.31   90.4   0.0   0      58.6
 338  16  86    1.0   0.85   91.5   0.0   0      16.4
 338  17  86    0.5   0.47   96.4   0.0   0       0.2
 338  18  86    0.0   1.36   99.5   0.0   0      -0.1
 338  19  86   -0.1   1.31  100.1   0.0   0      -0.2
 338  20  86   -0.1   0.08  100.1   0.0   0      -0.1
 338  21  86   -0.2   0.20  100.0   0.0   0       0.0
 338  22  86    0.3   0.02   99.9   0.0   0       0.0
 338  23  86    0.9   2.24   98.9   0.0   0      -0.1
 339   0  86    1.4   3.16   97.5   0.0   0      -0.2
                      .
                      .
                      .
 365  21  86    0.2   4.80   80.6   0.0 0         0.0
 365  22  86    0.1   7.01   85.3   0.0 0         0.0
 365  23  86    0.0   8.51   85.3   0.0 0         0.0
   1   0  87   -0.1   9.09   87.8   0.0 0         0.0
```

Daily Weather Data
Daily weather format is used when MTSTEP (Line A in List of Input/Output Files) is set to 1.

```
 337 86     0.0    -1.8    -1.5   1.62   0.0    14.2
 338 86     1.5    -1.4    -1.5   1.14   0.0    36.4
 339 86     2.7    -1.9    -0.5   1.78   8.9    11.5
 340 86    -1.5    -2.0    -1.5   0.84   0.0    22.2
 341 86    -1.2    -2.0    -1.4   0.37   0.0    23.0
 342 86    -1.1    -8.0    -3.0   1.07   0.5    49.5
 343 86    -2.4    -8.0    -8.2   1.20   0.0    54.5
 344 86    -1.1    -8.8    -9.1   1.21   0.0    72.1
 345 86    -4.9    -7.6    -4.9   0.42   0.0    24.1
 346 86    -0.2    -5.4    -3.6   0.92   1.3    18.3
 347 86     1.7    -3.0    -3.0   2.76   3.0    29.3
 348 86     2.8     0.2     0.2   3.32   1.5    54.0
 349 86     1.6    -3.3    -1.6   3.05   0.0    72.5
```

350	86	-2.2	-4.2	-3.0	1.12	0.0	29.2

Site Characteristics

```
PLOT 2 NT, A NO TILL, HEAVY RESIDUE PLOT  (SITE CHARACTERISTICS)  LINE A
 338  12  86  349  86                                             LINE B
 46 45  15.0 180. 12.0  750.                                      LINE C
 0  0  2 11  0  0.001   1      0   0   0   1   0   0              LINE D
 0.6  2.0  0.00                                                   LINE E
 0.0   .15                                      ****** SNOW       LINE G
 0  1.50                                        ****** RESIDUE    LINE H
 2.0   6000. 0.90  0.40 50000.   4.0                              LINE H-1
 0  0  0.25  0.0  1                             ****** SOIL       LINE J1
  0.000  10. 64. 26. 0.0  2.8  1360.  0.12 0.0  -0.20 0.60 4.35   LINE J3-1
  0.076  10. 64. 26. 0.0  0.0  1360.  0.12 0.0  -0.20 0.60 4.35   LINE J3-2
  0.152  10. 64. 26. 0.0  0.0  1350.  0.12 0.0  -0.20 0.60 4.35   LINE J3-3
  0.254  10. 64. 26. 0.0  0.0  1350   0.12 0.0  -0.20 0.60 4.35   LINE J3-4
  0.381  10. 57. 33. 0.0  0.0  1350.  0.14 0.0  -0.21 0.60 5.10   LINE J3-5
  0.533  10. 57. 33. 0.0  0.0  1400.  0.13 0.0  -0.21 0.60 4.90   LINE J3-6
  0.686  12. 60. 28. 0.0  0.0  1540.  .078 0.0  -0.27 0.60 4.80   LINE J3-7
  0.838  12. 60. 28. 0.0  0.0  1600.  .040 0.0  -0.39 0.60 5.20   LINE J3-8
  1.067   6. 54. 35. 0.0  0.0  1660.  .020 0.0  -0.55 0.60 5.70   LINE J3-9
  1.372   9. 67. 24. 0.0  0.0  1520.  .060 0.0  -0.31 0.60 5.10   LINE J3-10
  1.676   9. 65. 26. 0.0  0.0  1490.  .103 0.0  -0.24 0.60 4.40   LINE J3-11
```

```
SITE WITH HEAVY RESIDUE AND SAGEBRUSH CANOPY AND TWO SOLUTES                   LINE A
 338  12   86 350  86                                                          LINE B
 46 45   15.  270.0  12.0  1970.                                               LINE C
 1  0  1 11  2   00.001  1      0   0   0   1   0   0                          LINE D
 0.6  2.0  0.00                                                                LINE E
  0   -53.72  1.32   1.0                          ***** CANOPY                 LINE F
 1   1.0  0.25   7.0  100.  5.0   -300.   6.7E05   1.7E06                      LINE F1-1
 0.90  0.5  1.0  1.5  2.5  1.0                                                 LINE F2-1
  1.0  .15                                        ****** SNOW                  LINE G
 0  0.00                                          ****** RESIDUE               LINE H
 2.0   6000. 0.90  0.30 50000.   4.0                                           LINE H-1
 1.76E-09  0.0                                    ****** SALT #1               LINE I-1
 11*5.6                                                                        LINE I-2
 11*0.008                                                                      LINE I-3
 9.00E-09  100.                                   ****** SALT #2               LINE I-1
 11*0.0                                                                        LINE I-2
 11*0.007                                                                      LINE I-3
  0  0  0.15 0.0  1                               ****** SOIL                  LINE J1
 0.00  10. 60. 30.  0.0  0.0  1020.  1.16  0.0  -0.31  0.60 4.5   2.8 .005  LINE J3-1
 0.05  10. 60. 30.  0.0  0.0  1020.  1.16  0.0  -0.31  0.60 4.5   2.8 .005  LINE J3-2
 0.10  10. 60. 30.  0.0  0.0  1020.  1.14  0.0  -0.34  0.60 4.4   2.8 .005  LINE J3-3
 0.15  10. 60. 30.  0.0  0.0  1100.  1.18  0.0  -0.35  0.60 4.4   2.8 .005  LINE J3-4
 0.20  10. 60. 30.  0.0  0.0  1100.  1.18  0.0  -0.35  0.60 4.4   2.8 .005  LINE J3-5
 0.30  10. 60. 30.  0.0  0.0  1100.  1.18  0.0  -0.35  0.60 4.4   2.8 .005  LINE J3-6
 0.50  10. 60. 30.  0.0  0.0  1100.  1.18  0.0  -0.35  0.60 4.4   2.8 .005  LINE J3-7
 0.70  10. 60. 30.  0.0  0.0  1090.  1.54  0.0  -0.39  0.60 4.1   2.8 .005  LINE J3-8
 1.00  10. 60. 30.  0.0  0.0  1090.  1.54  0.0  -0.39  0.60 4.1   2.8 .005  LINE J3-9
 1.25  10. 60. 30.  0.0  0.0  1290.  3.09  0.0  -0.40  0.60 3.9   2.8 .005  LINE J3-10
 1.50  10. 60. 30.  0.0  0.0  1290.  3.09  0.0  -0.40  0.60 3.9   2.8 .005  LINE J3-11
```

```
SIMULATION FOR ASPEN TREES WITH UNDERLYING GRASS COVER
 250  24  89  250  90
 46 45   15.  45.0  12.0  1970.
 3  0  2 14  0   00.001  1        0   0   0   1   0   0
 0.6  6.5  0.00
  1   -53.72  1.32   0.0                          ***** CANOPY
 1   1.0   0.25  99.0  100.  5.0   -100.   1.70E5  3.30E5
 1   1.0   0.25   7.0  100.  5.0   -100.   1.70E5  3.30E5
 1   1.0   0.25   7.0  100.  5.0   -100.   3.80E4  7.70E4
 limbs.890
 aspen.890
 grass.890
  1.0  .15                                        ****** SNOW
 0  0.00                                          ****** RESIDUE
 5.0   6000. 0.90  0.30 50000.   4.0
  1  0  0.15 0.0  1                               ****** SOIL
 0.00  10. 60. 30. 0.0 0.0 1020. 1.16 0.0  -0.31  0.60  4.5  2.8 .005
 0.05  10. 60. 30. 0.0 0.0 1020. 1.14 0.0  -0.34  0.60  4.4  2.8 .005
 0.10  10. 60. 30. 0.0 0.0 1020. 1.14 0.0  -0.34  0.60  4.4  2.8 .005
 0.15  10. 60. 30. 0.0 0.0 1020. 1.14 0.0  -0.34  0.60  4.4  2.8 .005
 0.20  10. 60. 30. 0.0 0.0 1100. 1.18 0.0  -0.35  0.60  4.4  2.8 .005
 0.30  10. 60. 30. 0.0 0.0 1100. 1.18 0.0  -0.35  0.60  4.4  2.8 .005
 0.50  10. 60. 30. 0.0 0.0 1100. 1.18 0.0  -0.35  0.60  4.4  2.8 .005
 0.70  10. 60. 30. 0.0 0.0 1090. 1.54 0.0  -0.39  0.60  4.1  2.8 .005
 1.00  10. 60. 30. 0.0 0.0 1090. 1.54 0.0  -0.39  0.60  4.1  2.8 .005
 1.25  10. 60. 30. 0.0 0.0 1290. 3.09 0.0  -0.40  0.60  3.9  2.8 .005
 1.50  10. 60. 30. 0.0 0.0 1290. 3.09 0.0  -0.40  0.60  3.9  2.8 .005
 2.00  10. 60. 30. 0.0 0.0 1290. 3.09 0.0  -0.40  0.60  3.9  2.8 .005
 3.00  10. 60. 30. 0.0 0.0 1290. 3.09 0.0  -0.40  0.60  3.9  2.8 .005
 4.00  10. 60. 30. 0.0 0.0 1290. 3.09 0.0  -0.40  0.60  3.9  2.8 .005
```

Plant Growth Files

Input for leaves of aspen trees:

```
250  89  4.5  3.0 1.0  6.0  2.0   1.50   SEP 17
260  89  4.5  3.0 1.0  6.0  2.0   1.50   OCT
275  89  4.5  3.0 1.0  0.0  0.0   1.50   OCT
170  90  4.5  3.0 1.0  0.0  0.0   1.50   JUN 19
200  90  4.5  3.0 1.0  6.0  2.0   1.50   AUG
250  90  4.5  3.0 1.0  6.0  2.0   1.50   SEP 17
```

Input for limbs (and fall foliage) of aspen trees

```
250  89  4.5  5.0 1.0  1.0  0.25  .1   SEP 17
260  89  4.5  5.0 1.0  1.0  0.25  .1   OCT
275  89  4.5  5.0 1.0  1.0  1.25  .1   OCT 2
280  89  4.5  5.0 1.0  1.0  0.25  .1   OCT 7
260  90  4.5  5.0 1.0  1.0  0.25  .1   OCT
```

Input for growth of grasses

```
200  89  0.3  0.5 1.0  6.0  1.0  0.85   AUG
260  89  0.3  0.5 1.0  6.0  0.5  0.85   SEP 17
275  89  0.0  0.5 1.0  0.0  0.0  0.85   OCT 2
170  90  0.0  0.5 1.0  0.0  0.0  0.85   JUN 19
200  90  0.3  0.5 1.0  6.0  1.0  0.85   AUG
260  90  0.3  0.5 1.0  6.0  0.5  0.85   OCT
```

Surface Residue File

```
270 1982  5.0  9000. 0.90 0.30 50000. 4.0 Grassland residue before fire
273 2007  5.0  9000. 0.90 0.30 50000. 4.0

274 2007  0.5  1000. 0.60 0.50 50000. 4.0 Fire: Residue loss and albedo change

150 2008  1.0  1000. 0.60 0.50 50000. 4.0 Recovery each year after fire
274 2008  1.0  1000. 0.60 0.30 50000. 4.0

150 2009  1.0  1000. 0.70 0.30 50000. 4.0
274 2009  1.0  1000. 0.70 0.30 50000. 4.0

150 2010  1.0  1000. 0.80 0.30 50000. 4.0
274 2010  2.0  2000. 0.80 0.30 50000. 4.0

150 2011  2.0  2000. 0.90 0.30 50000. 4.0
274 2011  3.0  3000. 0.90 0.30 50000. 4.0

150 2012  3.0  3000. 0.90 0.30 50000. 4.0
274 2012  4.0  4000. 0.90 0.30 50000. 4.0
```

Model Output

The SHAW model will create up to 17 output files for various aspects of the simulated system as specified by the user. Model output can specified for hourly intervals, daily intervals, or multiple-hour intervals that multiply evenly into 24 hours (e.g. 2, 3, 4, 6, etc.). However, if sub-daily output is desired, sub-daily time steps (NHRPDT) must be specified. In most cases, output to the file is either the sum or average since the last output interval. The following briefly describes the output to the screen and each of the files.

Output to Screen

The SHAW model will generate output to the screen to indicate progress toward completion of the simulation. The model will update to the screen at desired intervals the day and hour for the simulation time, as well as the maximum and minimum number of sub-time steps that were necessary to solve the hourly or daily time steps during the output interval. If the model has difficulty reaching convergence for the energy or water balance equations, a message will flash on the screen indicating the time step where problems were encountered.

General Output File

The general output file is created for every SHAW run. This file contains the title of the run and values for many of the input and hard-coded parameters. A summary of the entire simulated profile may be output at specified intervals. Temporal output to this file represent the last time step prior to output, i.e. output for hour 24 will be average daily values for daily time steps and will be the value for the hour prior to midnight for hourly time steps. Caution: hourly output to this file can create rather large files for lengthy simulations.

Soil Profile Output

Output files may be created for simulated soil temperature, water content and/or water potential profiles. Each line in these files contains temperature (C), total or liquid water content (m^3/m^3) or water potential (m) for all nodes within the simulated profile at the desired output interval. Values represent average values over the output interval regardless of the time step used; if hourly output is desired, hourly time steps must be used.

Simulated total water content represents the total water content, i.e. ice plus liquid water content. A separate file may be output for liquid water content. Ice content for each soil node is output in the snow and frost depth output file.

Simulated water potentials are given in meters of water potential. While this may not be a common unit of water potential, it can easily be converted (1 m = 0.0981 bars = 9.81 kPa) and is very useful for specifying equilibrium water potentials above or below a water table, i.e. if the lower boundary is one meter below the water table, it has a water potential of +1.0 m.

Plant Canopy and Snow Profiles

Profiles of temperature and humidity through the plant canopy can be output at each time step of the model simulation. The user may specify whether to output relative humidity or vapor pressure. Output is omitted if there is no plant canopy.

Interpolated snow temperature profiles at 10-cm increments may be output at specified time intervals (up to daily). Unlike most of other output files, the output snow temperature is the instantaneous temperature at the output interval and not the average since the last output interval. Along with snow temperatures, snow depth and the number of temperature values are include at each output interval. The first (or 0-cm) temperature is the temperature at the snow-soil interface and the last temperature on a given date is the snow surface temperature, i.e. distances in this output file are from the ground up whereas distances elsewhere in the model are measured in the downward direction. Output is omitted if there is no snow at the output interval.

Surface Energy Flux

A summary of the surface energy balance may be specified for output intervals from hourly up to daily. For each output interval, net solar and long-wave radiation balance for the vegetation canopy, snow surface, residue and soil surface are given, respectively. Sensible, latent and ground flux heat values are given as well as incoming and reflected solar, and incoming and outgoing long-wave radiation. Sensible, latent and ground heat fluxes all assume positive values in the downward direction.

Water Balance Summary

A summary of the water balance for the simulated profile may be output at intervals from hourly up to daily. Values in mm for each output interval include: cumulative precipitation over the output interval; snowmelt, intercepted precipitation present on the canopy at the end of the interval; total evapotranspiration; total canopy transpiration; change in storage over the output interval within the canopy (not including intercepted precipitation), snow, residue, and soil layers; water lost to deep percolation by moving between the deepest two soil nodes within the soil profile; water lost to runoff; water ponded on the surface at the end of the output interval; cumulative evapotranspiration from the beginning of the simulation; and an error in the water balance for the time period.

Soil Water Flux

Vertical water transfer between soil layers can be output to the soil water flux file. Cumulative water transfer (liquid plus vapor) over the specified output interval is given in mm; positive values denote downward flux between nodes. Water flux between the bottom two nodes will coincide with the deep percolation output in the Water Balance Summary output file.

Plant Root Extraction

Water extracted from each soil layer by plant roots may be output at specified intervals. Output to this file is meters of water extracted from each soil layer. This output file may be used as input to subsequent SHAW runs as a Soil Source/Sink File after removing the two header lines. In doing so, water extraction by roots can be accounted for on a site where surrounding vegetation impacts the water balance of a site with little or no vegetation.

Sub-surface Lateral Flow

Sub-surface lateral flow may optionally be computed within the model by setting a non-zero value for the saturated lateral soil hydraulic conductivity. Lateral flow is assumed to occur only when the soil layer is saturated and is based on the slope. If slope is set to zero, no lateral flow will occur. This output file may be used as input to subsequent SHAW runs as a Soil Source/Sink File after removing the two header lines. In doing so, water entering the soil profile from an upslope profile can be accounted for.

Frost and Snow Depth

Frost, thaw, snow depth and snow water equivalent (SWE) may be output at specified intervals. Also contained in this file is ice content (m^3/m^3) for each soil layer. Output to this file represents conditions at the end of the output interval, not the average over the interval. Under conditions where there are several alternating layers of frozen and thawed soil, the thaw depth represents the deepest soil containing no ice that is underlain by frozen soil; output frost depth is the deepest soil depth containing ice.

Thaw and frost depth are computed by interpolating ice content over depth within the layer of maximum thaw or frost. If 100% of the water in a soil layer is ice, then the layer is assumed to completely frozen, and the computed frost depth will be midway between the soil node for that layer and next deepest soil node (assuming the next soil layer is not frozen). However, never is 100% of the water in the soil frozen. Thus, the next soil node will start to freeze before this condition occurs, which may result in a large change in the interpolated frost depth. This is particularly evident with large spacing between soil nodes. Additionally, a layer is assumed frozen only if it contains ice. A layer may have freezing temperature, but if it is sufficiently dry that the water does not freeze, it is assumed to be unfrozen. For these reasons, exercise caution when interpreting simulated frost and thaw depths.

Chemical Concentration Profiles

Output can be specified for total chemical concentration with the soil layer as well as the solute concentration in the soil solution. The total chemical concentration (termed salt concentration) for each species is defined as the total chemical within the soil layer per mass of soil (mole equivalents/kg of soil) and includes the chemical absorbed onto the soil and that in soil solution. A separate file contains the solute concentration in soil solution (mole equivalents/liter). Values from each file can be converted to ppm by dividing by the molecular weight of the chemical species. Output files will have a separate line of output at each output interval for each chemical species.