WRNSFMF User's Manual

Using and applying
the
USEPA WRENSS
hydrologic procedures for
snow dominated regions
"*Rocky Mountains*" and "*Continental Maritime*"
applicable to the
Foothills Model Forest
Hinton, Alberta, Canada

Version 1.0a, July 1996

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INSTALLATION AND SETUP

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System requirements

An IBM PC or compatible computer, 386, 486 or Pentium processor, 10 megabytes of available hard drive space, mouse and a VGA or higher resolution monitor. WRNSFMF runs as an application of the Microsoft ACCESS database program. It can be run from ACCESS version 2.0 under Windows 3.1, Windows 3.11, Windows For Work Groups 3.11, Windows NT or Windows 95. It can also be run from ACCESS version 7.0 under Windows NT or Windows 95.

ACCESS can be installed on a 386 based computer under Windows 3.1 with as little as 4 megabytes of random access memory, but it will run very slowly with frequent swapping of program components between memory and virtual memory on the hard drive. Microsoft recommends 12 megabytes of random access memory for proper operation of either version 2.0 or 7.0 of ACCESS. A 486DX4/100, or Pentium, with 16 megabytes of random access memory is highly recommended for reasonable performance.

MSGraph, which comes with ACCESS, must be installed on your computer in order to view graphical results. If your computer is on a network, check to see if MSGraph has been installed on your computer. Often it is installed on the server, but it must be on your computer for ACCESS to use it.

You should have a general familiarity with ACCESS before attempting to install or use WRNSSDR. You need to be able to start ACCESS, and to open various tables for viewing and entering data. You do not need to know how to program in ACCESS BASIC or to write ACCESS macros.

Installation

Only one file is on the furnished diskette - WRNSFMF.EXE. This file is a self-extracting archive which contains WRNSFMF.MDB, (the database containing the program forms and procedures), WRNSDAT.MDB, (the database containing the data tables), REGFUNCT.XLS (an EXCEL spreadsheet) and WRNSFMF.HLP, (a Windows help file).

To install WRNSFMF on your computer, create a directory on your hard drive for WRNSFMF.MDB, and optionally, a second directory for WRNSDAT.MDB. Copy WRNSFMF.EXE from the distribution disk to the directory created for WRNSFMF.MDB. In Windows 3.1, 3.11 or WFWG 3.11, click on "File", "Run" and type "d:\directory\WRNSFMF", where d:\directory is the disk and directory to which WRNSFMF.EXE was copied. In Windows95, click on START, select Run and do the same as indicated above. You may also use File manager (Windows) or Explorer (Windows 95) to select and install the program by double clicking on WRNSFMF.EXE. I suggest that you create a separate directory for WRNSDAT.MDB and copy this file to it as this makes it easy to backup your data. (After you copy WRNSDAT.MDB to a separate directory, you should delete it from the installation directory as it should only exist in one place on your hard drive.) The WRNSFMF.MDB file can always be re-installed at any time from the original diskette, but WRNSDAT.MDB will have data added to it as you use the program. (The WRNSFMF.MDB and WRNSFMF.HLP files require approximately 2 Mb of disk space. WRNSDAT.MDB initially requires approximately 500 Kb of disk space, however, this database will grow as your data is added to it.)

After you have completed the setup procedures outlined below, I suggest that you take the "quick tour" (see side bar below) to gain some familiarity with the WRNSFMF program before entering and conducting runs on your own data.

Setup

Unless you have some compelling reason to use ACCESS 7.0 (such as its your only version), I recommend that you use ACCESS 2.0. WRNSFMF runs almost 2.5 times faster under ACCESS 2.0 than it does under ACCESS 7.0, (even if it has been converted to an ACCESS 7.0 database for use within ACCESS 7.0)!

ACCESS 2.0 (All versions of Windows)

To complete the setup of WRNSFMF, start your copy of ACCESS 2.0. Select "File", "Open" and move to the directory where WRNSFMF.MDB is located. Click on "OK" and the program will load and display the main form.

From within ACCESS 2.0, select "File", "Add-ins", "Attachment Manager" and click on the box for each of the tables displayed. Click "OK", and ACCESS will either query you for the source directory for WRNSDAT.MDB, or refresh the existing attachments if they already exist. Click "Close" to exit the attachment manager when it has successfully attached or refreshed all linkages.

ACCESS 7.0 (Windows NT or Windows 95 only)

To complete the setup of WRNSFMF, start your copy of ACCESS 7.0. Select "File", "Open" and move to the directory where WRNSFMF.MDB is located. A dialog box will open giving you the choice of using WRNSFMF as an ACCESS 2.0 database or of converting it to an ACCESS 7.0 database. Although WRNSFMF will run in ACCESS 7.0 as an ACCESS 2.0 database, you will not be able to able to link the WRNSDAT.MDB database to it unless you have previously established the linked under ACCESS 2.0, or are willing to convert WRNSFMF.MDB to ACCESS 7.0. If you decide to change WRNSFMF.MDB to an ACCESS 7.0 database, then I suggest that you also rename it to something like WRNSFMF95.MDB so that it will be clear that this version of the database cannot be loaded under ACCESS 2.0. Click on "OK" and the program will load and display the main form.

From within ACCESS 7.0, select "Tools", "Add-ins", and if available, "Linked Table Manager". If "Linked Table Manager" is gray then you did not convert WRNSFMF to an ACCESS 7.0 data base. If "Linked Table Manager" is not gray, then click on "Linked Table Manager" and a screen will be displayed showing the attached tables to be linked. Click "Select All" and then click "OK". Access will query you for the directory where WRNSDAT.MDB resides. Browse or type in the correct directory. Select the WRNSDAT.MDB database and click "OK" to establish the linkages. Click "Close" to exit the Linked Table Manager.

USING WRNSFMF

> Quick Tour. If you are in a hurry to see how the program runs, click on the "Scenario Definition and Simulation" button. When the "Define and Run Scenarios" form opens, click on the "Run" button. The program will run the currently selected scenario and display the results. Click on the "Clear Data & Return" button to return to the "Define and Run Scenarios" form. That's all there is to running an existing scenario.

ACCESS Forms

ACCESS is an event driven database. You cause ACCESS to carry out various operations by clicking on "buttons" or data fields on a form. Clicking means to position the mouse pointer over a button and push the left mouse button (left on a right-handed mouse, right on a left-handed mouse). Some of these buttons or data fields have an underlined letter in their caption. You may push the "Hot Key" combination (the Alt key and the underlined letter key at the same time) to carry out the same action as clicking on the field with the mouse.

If you are using the default colors suggested by Microsoft for any of the Windows versions, the active form will have a blue bar along the top. Inactive forms will have a gray bar. The active form is said to have the focus. Only one form can have the focus at any one time.

On each form one field or button will have the focus. A field will be highlighted, generally in reverse video, if it has the focus. A button will have a dotted outline around the button text when it has the focus. Whenever a button has the focus, the enter key, as well as the mouse or hot key combination, can be used to carry out the button's function. Context sensitive help is available by pressing the "F1" key while the focus is on most of the buttons or data fields on the forms.

Main form

This first form (Figure 1), which will always be displayed upon startup, is a main switchboard which displays the name of the

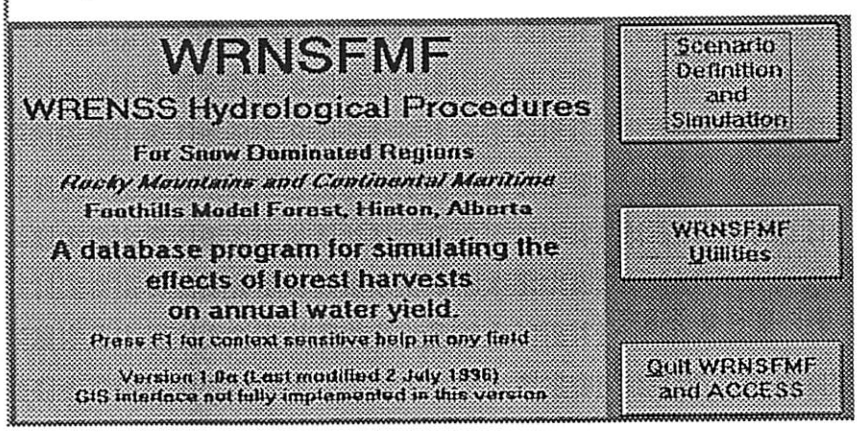


Figure 1. Screen (form) displayed upon opening WRNSSDR.

version of the WRNSFMF program, the version number, the date that this version was last updated and a number of "buttons" to access features of the program. Note that the "Scenario Definition and Simulation" button has the focus at this time. Press Alt+S, press the return key or click on "Scenario Definition and Simulation" to go to the primary form for interaction with the hydrologic procedure.

Define and Run Scenarios form

The "Define and Run Scenarios" form (Figure 2 - single unit view; Figure 3 - units in tabular view) is used to carry out the following steps to define a scenario. 1) Assign a name and WRENSS

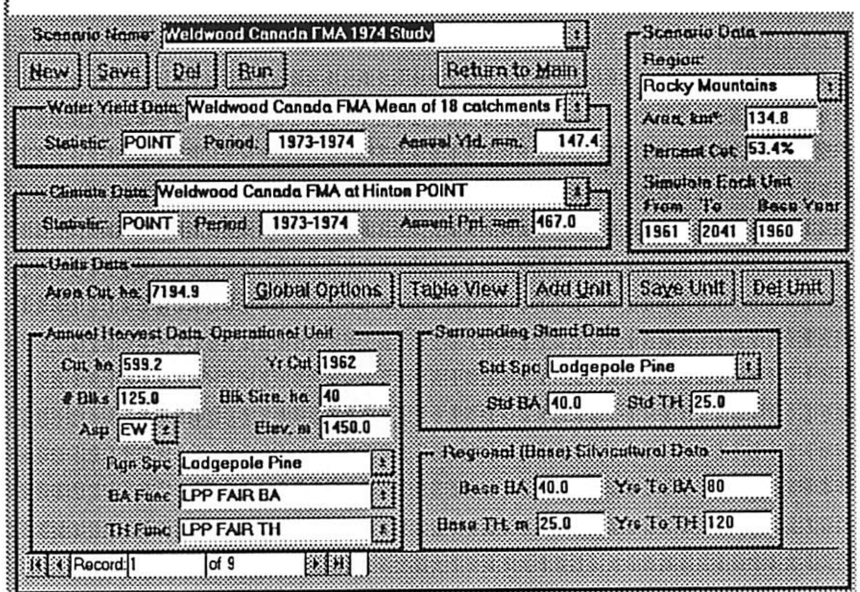


Figure 2. Screen (form) for defining and running scenarios, single form display of harvest units.

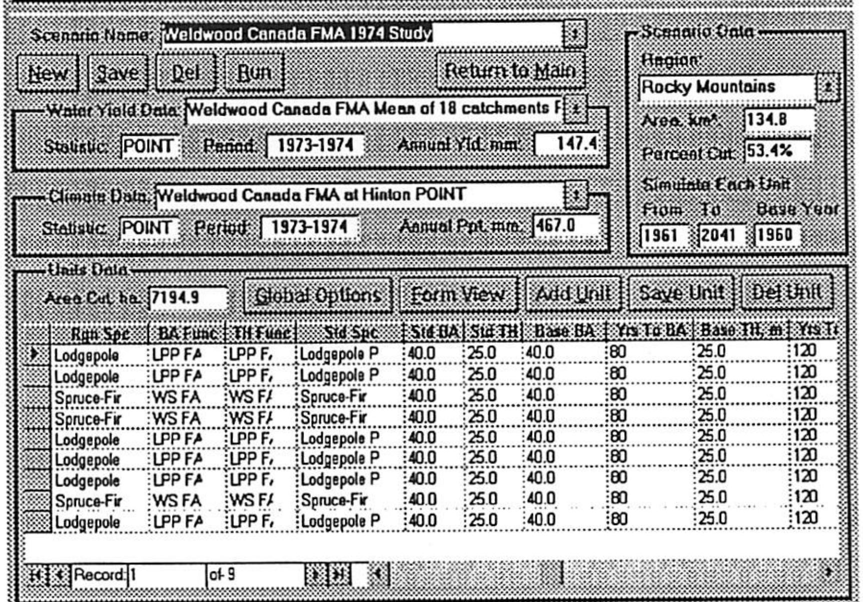


Figure 3. Screen (form) for defining and running scenarios, tabular display of harvest units.

hydrologic region to a scenario. 2) Enter information for the harvest blocks or hydrologic units that will be a part of that scenario. 3) Select the water yield and climate data that will be used in the scenario. 4) Set the number of years to simulate, including the year to use as a base value for yield increases.

A scenario consists of a watershed, one or more hydrological or harvested units, the appropriate climate, water yield data and the run duration. A scenario should answer some question, such as "what will be the effect of harvesting, over the next 50 years, 100 ha each year for the next 10 years on water yield from a 100 km² watershed?".

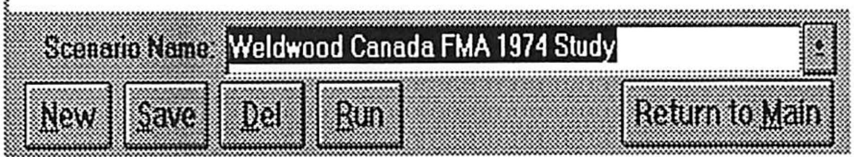


Figure 4. Portion of form for defining and running scenarios. Name scenario and/or select existing scenario and carryout indicated scenario operations.

The first scenario in the database will be displayed and the focus will be on the **Scenario Name** field when the "Define..." form opens (Figure 4). You may select from among all currently defined scenarios by clicking with the mouse on the arrow to the right of the **Scenario Name** field. A list of those defined will drop down from which you can select one by clicking on it with the mouse. You may also create a new scenario (click on the **New** button), delete the current scenario (click on the **Del** button), save the current scenario (click on the **Save** button, or run the scenario by clicking on the **Run** button. The **View Results** button will be visible the first time that you open this form. If the results for the current scenario (the scenario displayed in the name box) are still in the database, clicking the **View Results** button will open a form with a table and graph of those results. If no results for the current scenario are in the database, a message will inform you of this fact, and the **View Results** button will no longer be visible. The arrow to the right of the **Region** field is used to select a WRENSS hydrologic region for the scenario. Only the *snow dominated regions* will be displayed, and if your version of WRNSFMF is specific to your organization, only those snow dominated regions applicable to your specific area will be displayed.

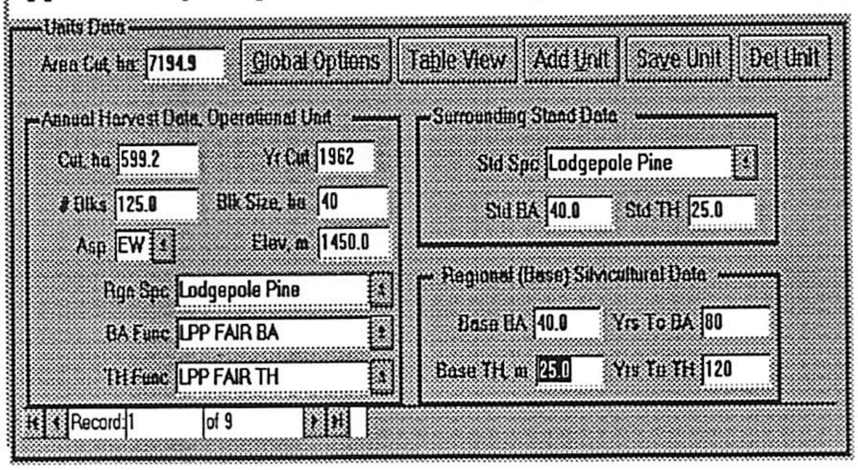
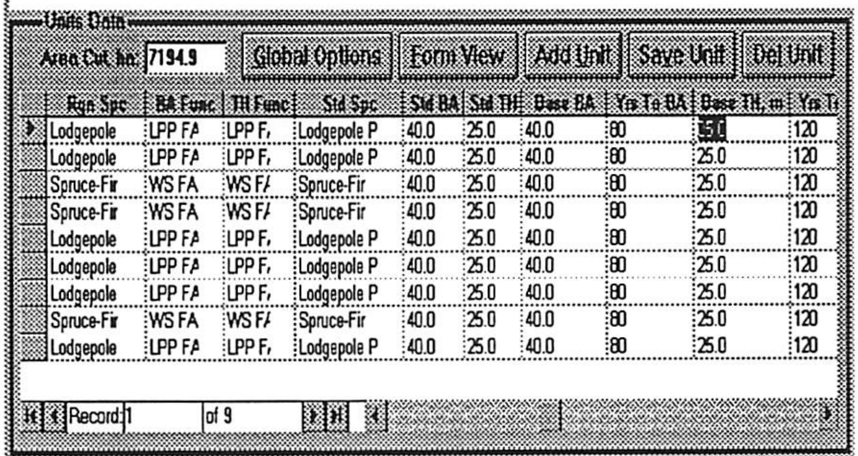


Figure 5. Bottom portion of form for defining and running scenarios. Single unit display.

The information on harvest blocks or hydrologic units is entered in the **Units Data** group in the bottom half of the form (Figure 5). Initially only the information for one unit will be displayed. The selector arrows at the bottom of the **Units Data** group can be used to display the remaining units, if any, that have been defined for the scenario. These data can be viewed in two



Units Data
Area Cut ha: 7194.9 | Global Options | Form View | Add Unit | Save Unit | Del Unit

	Rgn Spc	BA Func	TH Func	Std Spc	Std BA	Std TH	Base BA	Yrs To BA	Base TH, m	Yrs T
▶	Lodgepole	LPP FA	LPP F,	Lodgepole P	40.0	25.0	40.0	80	[illegible]	120
	Lodgepole	LPP FA	LPP F,	Lodgepole P	40.0	25.0	40.0	80	25.0	120
	Spruce-Fir	WS FA	WS F/	Spruce-Fir	40.0	25.0	40.0	80	25.0	120
	Spruce-Fir	WS FA	WS F/	Spruce-Fir	40.0	25.0	40.0	80	25.0	120
	Lodgepole	LPP FA	LPP F,	Lodgepole P	40.0	25.0	40.0	80	25.0	120
	Lodgepole	LPP FA	LPP F,	Lodgepole P	40.0	25.0	40.0	80	25.0	120
	Lodgepole	LPP FA	LPP F,	Lodgepole P	40.0	25.0	40.0	80	25.0	120
	Spruce-Fir	WS FA	WS F/	Spruce-Fir	40.0	25.0	40.0	80	25.0	120
	Lodgepole	LPP FA	LPP F,	Lodgepole P	40.0	25.0	40.0	80	25.0	120

Record: 1 of 9

Figure 6. Bottom portion of form for defining and running scenarios. Tabular display of units.

ways; with each unit displayed in single form view or with each unit displayed on one line in a tabular view. A button, **Form View** or **Table View**, will be displayed depending upon the current content of the display. Click on this button to toggle between the

Figure 7. Select water yield data to be used as baseline for simulations of harvest effects.

two views (Figure 6). The **Add Unit**, **Save Unit**, and **Del Unit** buttons function for each unit in the same manner as those above for the entire scenario. The **Add Unit** button is useful as it will create a copy of any selected unit and add it to the collection, where it can then be edited to other values.

The water yield data you enter is used to establish a base for

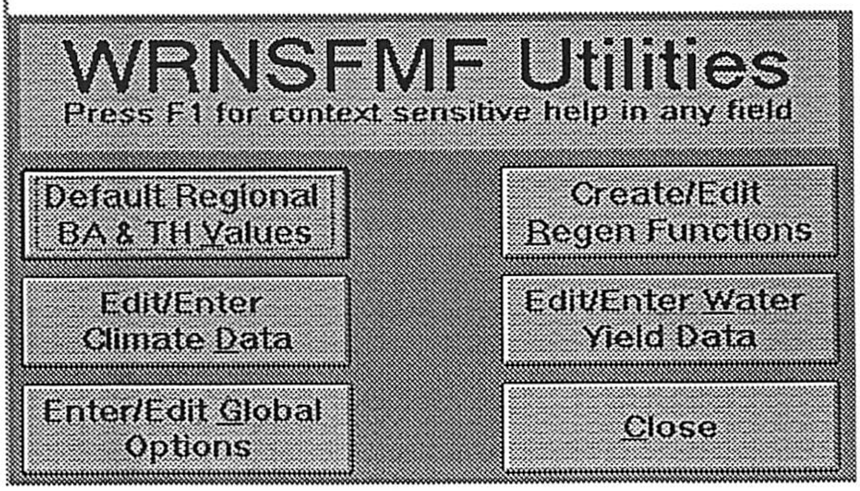


Figure 8. Utilities switchboard.

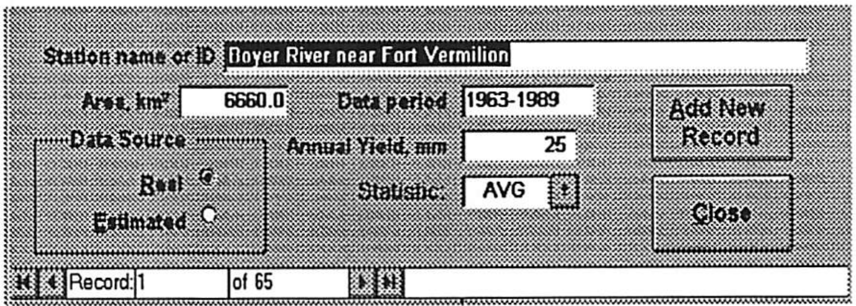


Figure 9. Form for entering or changing water yield data in database.

comparison of simulated increases (Figure 7). The data displayed in the **Water Yield Data** field must be in the database. You cannot enter new water yield data from this form. It must be entered from one of the utilities selectable from the main form (Figures 1, 8 and 9).

The water yield data displayed here should be as representative of normal water yield from the area of your scenario as possible. I have included maximum, minimum and average water yield data in the database for a number of watersheds in northwestern Alberta.

Figure 10. Select climate data to be used in simulation run.

The climate data you select (Figure 10) sets the precipitation, precipitation gauge type, wind, wind direction, and information on the number of days with snow. The data displayed in the **Climate Data** field must be in the data base. You cannot enter new climate

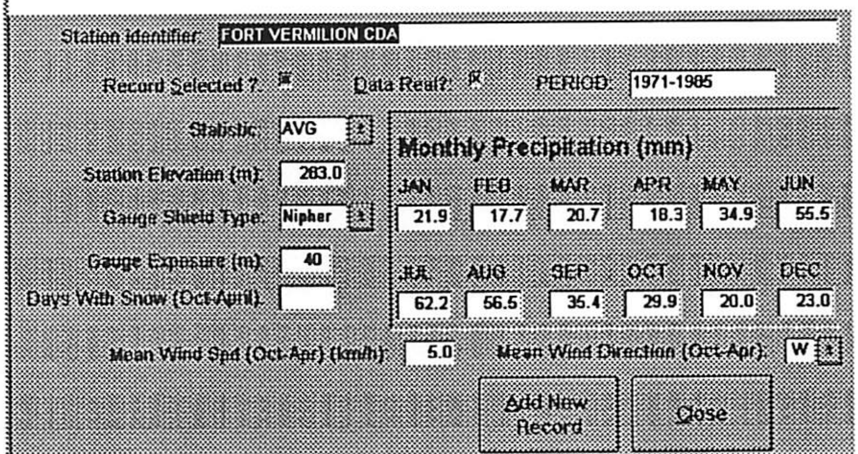


Figure 11. Form for entering or changing climate data in database.

data from this form. It must be entered from one of the utilities selectable from the main form (Figures 1, 8 and 11).

The **Scenario Data** portion of the form (Figure 12), contains the information on the extent and duration of your simulation. You can select any of the WRENSS regions applicable in your area from the **Region** field. The **Area** is the total area for your scenario. WRNSFMF requires a scenario area which must be entered; the other data items are optional but desirable. Normally a scenario is

In one of the examples "Weldwood Canada FMA 1974 Study" the area is the total area of thse logged and unlogged watersheds evaluated. These were widely separated locations within the five working circles of that 7800 km² forest management area.

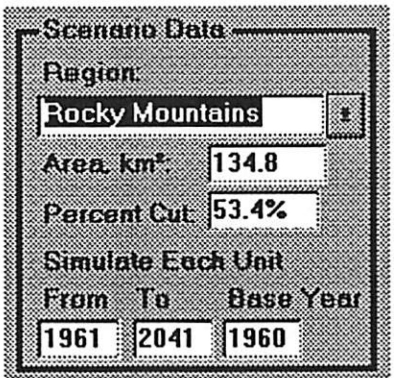


Figure 12. Set the region, watershed area, and number of years for simulation run.

If you change the region that was used in an existing scenario, then you must also select species defined for the new region in each unit.

See "Example scenario, harvest before and after base year". Why is the yield negativee with respect to the base year after cutting has ceased?

defined for a contiguous watershed, and the area would be the total of that watershed.

The "Simulate Each Unit" portion of the form (Figure 12) allows you to set the duration of the simulation run. The "From" and "To" should contain the year to begin and end the simulation respectively. The "Base Year" is the year you want to compare water yield changes against. It is not used if the global option "AutoCalibrate" (Figure 13) is not selected (checked). It can be set to a year before any harvest has occurred, or to any year during the simulation. It's default is the year prior to the "From" year, and this ordinarily simulates a base water yield before any harvest has occurred. Setting the base year to a year between the "From" and "To" year simulates a base water yield that will produce negative water yield increases from those harvests that occurred before it, and positive water yield increases for those subsequent.

Harvest information is entered in the **Annual Harvest Data,**

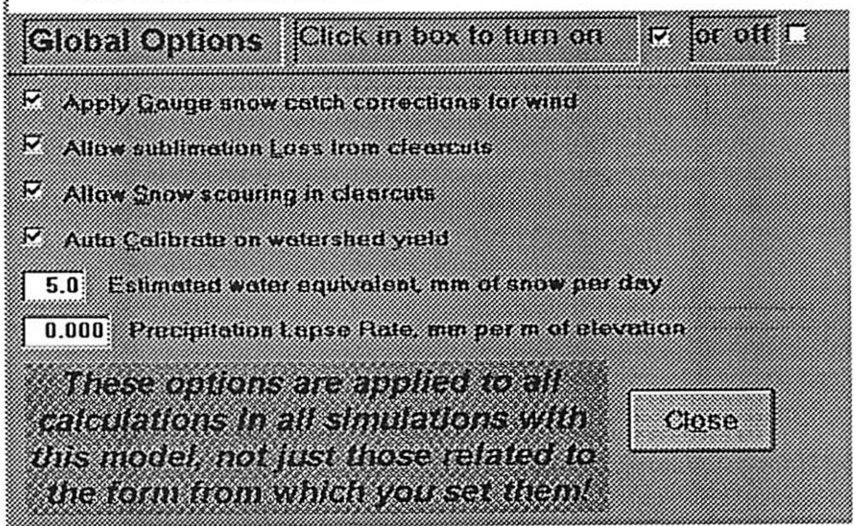


Figure 13. Form for setting or changing global options.

During simulation, WRNSFMF constrains the area logged in any given watershed to 95% of the total arsea of the watershed, as the model requires some residual stand for deposition of the difference in snow accumulation between clearcuts and treed areas.

Operational Unit portion of the form (Figure 14). The main items of concern are the cut area, the year cut, the block size, block aspect, regeneration species, and the basal area and tree height growth functions. The elevation is not necessary at the present time. It will eventually be used to with a lapse rate to help estimate precipitation on the unit.

Each unit should represent a reasonably hydrological homogenous area. For instance, all of the northerly aspect blocks harvested in the same year could

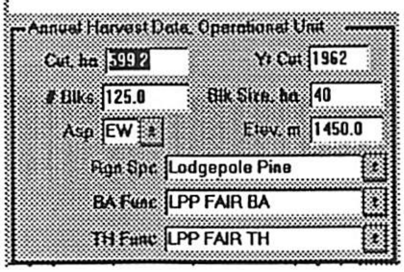


Figure 14. Enter cut block harvesting information (one operational or hydrologic unit).

As I demonstrate with data taken from 18 separate catchments on the Weldwood Forest Management Area, Hinton, Albserta, the watershed does not have to be a contiguous land area. It may be a composite for which one has the required areal and harvest data.

be grouped together as one operational unit. You can have any number of operational units in a scenario, but each unit must be simulated for all years of the run, and the more units there are, the longer the computational time. So always group cut blocks if they are reasonably similar.

The regeneration species should be the species you expect occur on the site, but must be selected from the list of those presented (these are all that were defined in WRENSS for the selected region). It need not be the same as that harvested or of the surrounding stand. The basal area and tree height functions should be specific to your area. I have included some that I have derived from the Alberta Forest Service's phase III inventory, but these should only be used as rough estimates. You can enter the names and coefficients for your regrowth curves in the **User**

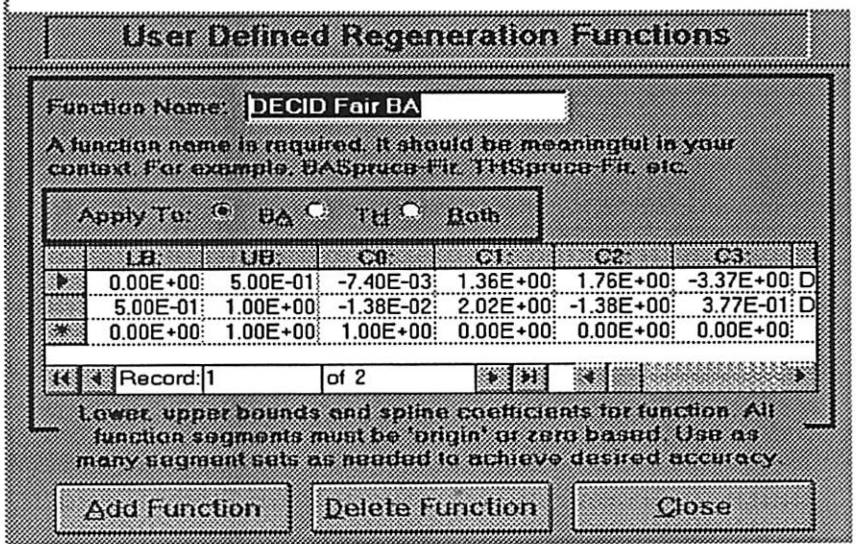


Figure 15. Form for entry of user-defined basal area and height growth functions.

Defined Regeneration Functions form (Figure 15) selectable from the utilities switchboard (Figure 8). I have also included an EXCEL spreadsheet (REGFUNCT.XLS) with my derivations that you can use as an example of the form that these function must have for use in WRNSFMF

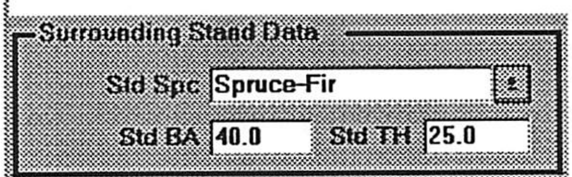


Figure 16. Enter data for stand surrounding harvested block.

The **Surrounding Stand Data** block (Figure 16) is used to describe the stands immediately adjacent to the operational unit. Only those species applicable to the selected WRENSS region will be displayed for selection. You may enter new values for stand basal area and tree height, or accept the defaults.

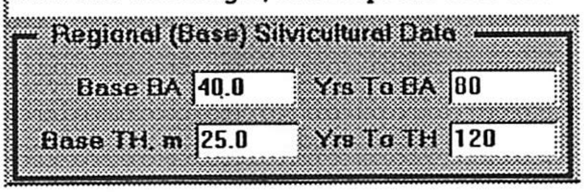


Figure 17. Verify or change silvicultural parameters for region.

The **Regional (Base) Silvicultural Data** block (Figure 17) is used to describe

Figure 18. Tabular presentation of default basal area and height parameters for each WRENSS region.

Region	Species	BaseBA	BaYears	BaseTH	ThYears
[illegible]	Deciduous	30	30	20	30
CM	Lodgepole Pine	40	80	25	120
CM	Spruce-Fir	40	80	25	120
CM	Western Larch	40	80	25	120
CS	Deciduous	30	30	20	30
CS	Lodgepole Pine	40	80	25	120
NE	Coniferous	40	80	25	120
NE	Deciduous	30	30	20	30
NW	Deciduous	30	30	20	30
NW	Douglas-Fir	40	80	25	120
NW	Hemlock-Spruce	40	80	25	120
RM	Deciduous	30	30	20	30
RM	Lodgepole Pine	40	80	25	120
RM	Ponderosa Pine	40	80	25	120
RM	Spruce-Fir	40	80	25	120
		0	0	0	0

the silvicultural potential of the general area. The basal area, tree height and the number of years to achieve these should be the values you would anticipate for this stand at maturity. You may enter new value or accept the defaults.

You may set different values for the defaults for the regional base data (Figure 18). These defaults are also used for the surrounding stand basal area and tree height.

Running scenarios

The "Run" button (Figure 4) sets a number of things in motion. First, the current information for the common scenario data and all of the units is saved to appropriate tables in the WRNSDAT.MDB database. The program examines the global options and sets those that have been selected. Then the data for the first unit is loaded into an operational array.

What happens next depends upon whether or not the global option "AutoCalibrate' was selected. If it was, and this is highly recommended, then WRNSFMF calculates a base water yield by adjusting the amount of precipitation until the water yield calculated for the "Base Year' is the same as that in the "Annual Yld, mm" as selected by the "Water yield Data" name. This calibrated precipitation is then used in all subsequent years of the simulation run for that unit, and the base water yield is subtracted from that simulated to obtain the water yield increase. Note that some harvest can have occurred prior to the base year, and these harvests must be entered, along with their year of occurrence in the "Units Data" (the simulation duration should also include these years). The calibration value displayed with the simulation results is the amount that precipitation has been multiplied by in order to calibrate the scenario to the watershed. That is, a calibration value of 1.20 means that the precipitation was increased by 20%. If the precipitation data is accurate and representative of the watershed being simulated, then calibration values between 0.85 and 1.15

are generally obtained.

If "AutoCalibrate" is not selected, then the precipitation is not adjusted. Simulated water yields are compared against the selected water yield data, and may be negative or positive. Some form of calibration is really necessary to get meaningful simulation results. Either the user can adjust the amount of precipitation himself, or allow WRNSFMF to do it by selecting the autocalibrate option.

In either event, WRNSFMF steps through the years, simulating the water yield change caused by each unit starting with the "From" year and ending with the year in the "To" field. It then area weights each unit's contributions and sums them within each year. These summed results are stored in the table "rtbl Operational Units Results" in the WRNSDAT.MDB database by scenario name, year, delta yield, and percent change. These data are then displayed in tabular and graphical presentation on the Scenario Results form.

Scenario Results form

The Scenario Results form (Figure 19) is automatically opened upon completion of each simulation run. The results are displayed in tabular and graphical form and summarized by calibration value (if AutoCalibrate is selected), maximum absolute water yield increase, maximum percentage of base yield increase, and the base yield. You may discard the results by clicking on "Clear Data and Return", which deletes the results data from the WRNSDAT data base, and returns you to the Define and Run Scenarios form. You may also print the data table ("Print Table" button) to any defined printer in Windows, or output the data for further analysis ("Output to File" button) as an Excel worksheet, in Rich Text

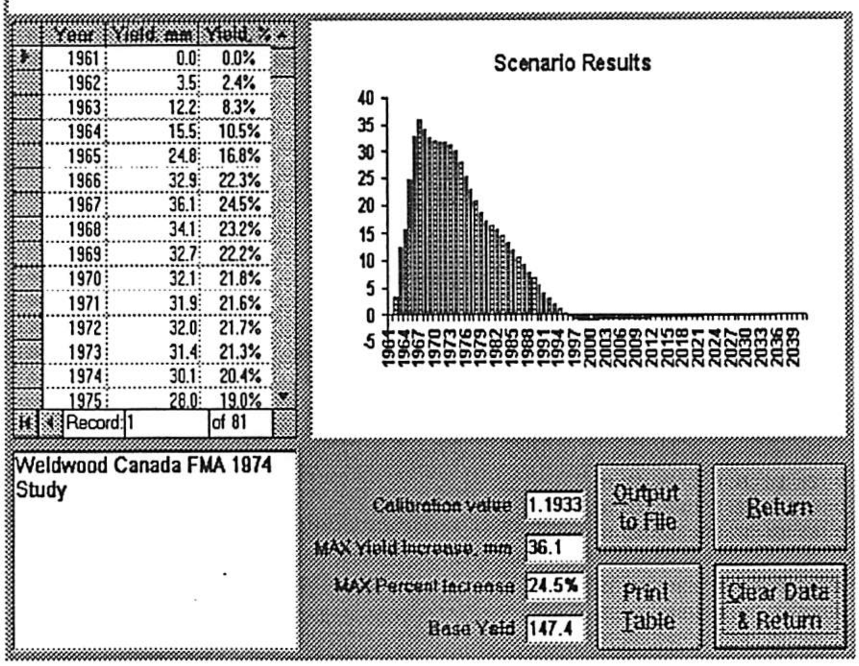


Figure 19. Visual output of scenario simulation. Can be output in various file formats for further analysis.

Format for use in Microsoft Word or other word processors, or as MS-DOS Text (comma delimited) for import into a variety of databases or spreadsheets. You may also return ("Return" button) to the Define and Run Scenarios form leaving the result's data intact for future viewing.

Data requirements for WRNSFMF

> Generated runoff is defined as precipitation minus all of the losses that will occur. It is water that will eventually become streamflow, but may be retained in storage within the watershed or stream channel for some indefinite period before it flows past the watershed boundary (US Army 1956).

The data required to operate the WRENSS procedure are minimal compared to any other hydrological model. The WRENSS procedure simulates annual yield change. This it does very well with only seasonal precipitation and forest cutting information as input data, i.e., at most 12 monthly precipitation values and basal areas for uncut and cut stands. Those desiring to simulate *daily* water yield need to be aware that the data requirements for such simulation are in the order of 1000 to 2000 times that of the WRENSS procedure. Daily precipitation, air temperature, relative humidity and solar radiation are the minimum required to use simulation models that produce daily generated runoff. If one wishes to route the daily water yield values to a specific stream reach, then either a hydrograph for calibration, or extensive measures of watershed and channel characteristics, which may also vary through time, are also required. Therefore, the next step beyond the use of the WRENSS approach is a major undertaking.

> The term xBase refers to all data bases based on the dBase structure. These include Fox Base, Alpha 4, dBase III, IV and successors.

Data requirements are somewhat greater for the WRNSFMF procedure than for WRENSS because of the corrections to precipitation data, and the possibility of simulating time-trends and/or the cumulative effects of multiple harvested units. In addition to the data required for the WRENSS procedure, WRNSFMF requires growth curves for basal area and height as a function of time (Figure 14). It also requires data on the precipitation gauge type and exposure and either data or estimates of wind speed and the number of days with precipitation during the winter season. When harvested block data are generated by a Geographical Information System (GIS), other parameters such as the elevation of each block, the width of each block in the windward direction, and wind direction at that block can also be used as input data to refine the precipitation data and snow distribution parameters.

The structure of ACCESS allows one to readily import data from a variety of sources, including xBase data bases, Lotus 1,2,3, Excel, and ASCII files. All input data used by WRNSFMF is located in a data base separate from the model's code and forms.

> In ACCESS, Select File|Open, open the WRNSDAT data base; select File|Import and follow the instructions for importing data.

Climate data for WRNSFMF

Climate data is held in a table "tbl Climate data" in the WRNSDAT data base, and can be entered manually from within WRNSFMF (select" WRNSFMF Utilities" from the main form (Figure 1) and then select "Edit/Enter Climate Data" (Figure 14) to access

> Whether the climate or water yield data is real or not is irrelevant to WRNSFMF. This information is included only to give the user an indication of the quality of the data.

a form for manual entry or viewing of climate data, Figure 10). Data may be imported to this table from other data bases, spreadsheets, comma delimited tables or fixed format tables. All data in a record (one year's data in the table) may be flagged as "Real", meaning it is actual data from the indicated source. If this box is not checked, then the data is assumed to be estimated.

The "Statistic" field is user information concerning the type of data contained in the record. "Point" means that the data is from a given year as listed in the "Period" field as the same beginning and end year, e.g., 1996 -1996. "AVG", "MAX", and "MIN" refer to the average, maximum and minimum data that occurred during the period indicated. An entry in this field is not required, but it is useful information to have in designing harvesting scenarios. These various statistics are not generated by WRNSFMF; the user must generate these, and a spreadsheet is a convenient tool to use for this purpose. The data for the period in question can be exported from point data in a data base, imported into a spreadsheet, the particular statistic extracted or calculated, and imported into WRNSDAT.

> As an example if the seasons precipitation was 100 mm, 100 mm divided by the default value, 5 mm/day, would imply that snow fall occurred during 20 days in that season.

Wind data may or may not be available. If not, then an estimate of 5 km/hr average for the entire winter period is available as a default.

Likewise, the number of days with snow may not be available. One can enter an optional value in the "Enter/Edit Global Options" form (Figure 13) to estimate the number of days with snow. This estimate is derived by dividing the winter precipitation, in mm, (this division happens at run time within WRNSFMF) by an estimated snow fall, in mm, that occurs during each snow event in your area. A default value of 5 mm/day is assumed if no value is entered.

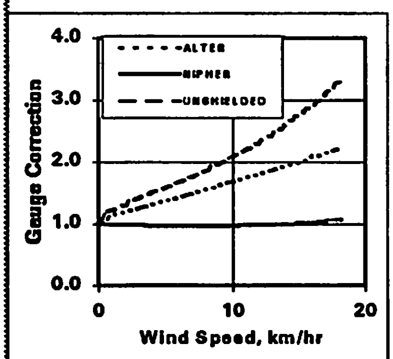


Figure 20. Wind speed corrections applied to snow catch for several precipitation gauge wind shields. Only those most commonly used were tested by Goodison (1981)

Only those precipitation gauge shields for which Goodison (1981) provided corrections are selectable as "Gauge Shield Type" (Figure 20). The default is "Unshielded" meaning that corrections for wind effects on an *unshielded* gauge will be applied. If gauge corrections for this particular data set are not desired, select "None": if gauge corrections for *all* data sets are not desired, uncheck this option on the global options form (Figure 13). Gauge corrections are only applied to precipitation during the winter season.

Climate data can be from a station on your particular watershed (Real data) or an estimate from one or more nearby stations. Data from existing climatic stations in the near vicinity should be entered into the table for use when needed. Climate data for the watershed in question can often be estimated from these real data sets. I find it convenient to define climate "station" data for each scenario with an appropriate name and climate data

> For example, if I was examining a watershed in the vicinity of climate station named "Beaver Lookout", I might name my station "Beaver Lookout 1996 - 2010 AVG" to indicate the where the data originated, the period of data that I used in my statistic, and that it is average data for that period.

In ACCESS, Select File | Open, open the WRNSDAT data base; select File | Import and follow the instructions for importing data.

I find it convenient to define watersheds for each scenario with an area appropriate to my scenatio, and water yield from a nearby gauged watershed as an estimate of the real water yield from mine. For example, if I was examining a watershed in the vicinity of Beaver Creek (Every state or province has a beaver creek, right?), I might name my scenario "Beaver Hill 1996 - 2010 harvests (Beaver Creek AVG)" to indicate the location of the watershed, duration of harvests considered and the fact that I am using the average flow from Beaver Creek in my simulation.

from a nearby station as an estimate of the real climate data at mine.

Water yield data

Water yield data is held in a table "tbl Water Yield Data" in the WRNSDAT data base. Water yield data is not available to WNRSFMF until it exists within this table. Data may be imported to this table from other data bases, spreadsheets, comma delimited tables or fixed format tables. Data may also be entered manually(select" WRNSFMF Utilities" from the main form and then select "Edit/Enter Water Yield Data" Figure 9). All data in a record (one year's data in the table) may be flagged as "Real", meaning it is actual data from the indicated source. If this box is not checked, then the data is assumed to be estimated.

The "Statistic" field is user information concerning the type of data contained in the record. "Point" means that the data is from a given year as listed in the "Period" field as the same beginning and end year, e.g., 1996-1996. "AVG", "MAX", and "MIN" refer to the average, maximum and minimum data that occurred during the period indicated. An entry in this field is not required, but it is useful information for the user to have in designing harvesting scenarios. The various statistics are not generated by WRNSFMF; the user must generate these, and a spreadsheet is a convenient tool to use for this purpose. The data for the period in question can be exported from point data in the data base, imported into a spreadsheet, the particular statistic extracted or calculated, and re-imported into WRNSDAT.

Water yield data can be for a gauged watershed, or one for which no real data is available. That for existing gauged watersheds in the near vicinity should be entered into the table for use when needed. Data for watersheds in question can often be estimated from these real data sets.

Harvest data

The harvest data is the most site-specific data required. These data are what really defines the change in water yield. It is imperative that these data be as realistic as possible in order to simulate realistic changes in water yield. These data are contained in the WRNSDAT data base in "tbl Operational Units" and may be imported from a GIS or similar source, or may be entered manually (Figures 5 and 6) during the development of a scenario definition. You will also have to enter or import the name of these data sets in the scenario name field of the table "tbl Operational Units Control" (in WRNSDAT), otherwise the imported data will not appear in the list of defined scenarios. All units within a given scenario must have the identical scenario name.

An entry must be made for all data items in this table. Defaults for elevation, aspect, base BA and TH, regeneration species, stand species, etc. are available while others such as area cut, block size, year cut, aspect, elevation etc. must be entered. The separate entries for area cut and block size allow one to group a number of blocks harvested in the same year into one composite area. The average size of the blocks in this composite area is used in defining the effects of wind and opening size on snow accumulation and loss. If the unit contains more than one cut block, than an average area for all of the cut blocks must be entered in the "Blk Size" field, or the number of blocks in the average entered in the "# Blks" field.

Note that the regeneration species need not be the same as that originally on the cut block or that of the surrounding stand. This allows for the regrowth of a "pioneer" species such as aspen in a predominantly coniferous stand. The default parameters for stand and regional basal area and tree heights and their respective years to accomplish are often suitable for a first "what if" look at the potential water yield increases from a particular harvest scenario, which can be fine tuned as more realistic site data and regrowth functions become available.

Formulating scenarios

All scenarios must be derived for a watershed. A watershed should be defined as the area above some point in a stream where the flow is of consequence to either instream users or to one who would be affected by the outflow. The watershed is the container for the harvested units and its area must be the total area of all of the harvested, inoperable and unlogged blocks.

A user can enter one or any number of harvest units to the watershed from within this form. As new blocks are entered, their individual areas are added to the total cut area and the percentage of the watershed area that is cut is updated.

First look or a quick "what if"

The first approach one should use in examining the effect of harvest on a particular watershed is take a quick look at the watershed and harvest data and create a "worst case" scenario, generally with only one unit, to see if there is any reason for greater detail. I consider a "worst case" scenario one in which the maximum probable amount of harvest that will occur on the watershed takes place in one or at most a very few years.

It is easy to get carried away by the ease with which one can create new units and add detail to the harvest scenario. If you can group various harvested blocks by year of harvest, aspect or elevation, then you should do so, as their individual appearance in the table of harvest units will only increase computation time, and not produce comparably better resolution in the output data.

More details - multiple harvests through time

Probably the most useful simulations are those that estimate the cumulative effects of sequential harvests through time. WRNSFMF is particularly useful in this context because it allows various regrowth functions to operate on a block independent of other blocks. The shape of the growth function, and the number of years to reach an anticipated basal area or tree height can be entered for each harvested unit. This feature allows a great deal of flexibility and realism to be incorporated in any simulation.

Data sets can be produced manually or from a GIS. A GIS should be able to provide very detailed data on existing harvested units that would be time-consuming to acquire manually. It should also be able to provide details on planned harvesting units. The "Weldwood Canada FMA 1974 Study" (data from this study is on most of the example figures) is a good example of what can be accomplished with manual data entry into WRNSFMF when one has historical data from a number of watersheds harvested at various times. These data from Swanson and Hillman (1977), are for harvested blocks ranging in average age from 8 to 12 years since harvest. In this simulation The simulated yield increase in 1974, the year for which we have actual yield data from these watersheds, is 36 mm compared to 41 mm measured. These data could be more detailed and refined from within a GIS data base, and a more realistic regrowth function - especially for the first few years after harvest, actual block aspects and an increase in the number of units so that all of those blocks harvested within a given year could be included with the actual year of harvest to fine-tune the output.

SOLVING HYDROLOGIC PROBLEMS USING WRNSFMF

Estimating annual yield change

Annual yield changes are the easiest to evaluate, but are relatively useless without a context. There are at least two uses that annual yield changes can address. 1) A need for more water, and 2) a need for less water. Most of the research on the influence of forest harvest on water yield has been with respect to increasing water supply. Watershed management as a topic for study in the United States has been primarily aimed at devising ways to manage a forest to increase the amount of water for down stream users. The publication of the WRENSS handbook (USEPA 1980) was a direct result of government interest in determining the effects of forest harvest on streamflow and related water resource values. Thus, the evaluation of annual yield changes should address a question - a question of how or if a water yield change will affect a water user.

The first thing that needs to be done in determining the affect of a water yield change is to determine <u>who</u> might be impacted and the <u>base</u> upon which the change will be imposed. It is unlikely that any amount of forest harvest will increase annual yields by more than 50 to 100 mm. If the base is already in the neighborhood of 500 to 1000 mm and water is a surplus commodity, than the change introduced by forest harvesting operations will probable not be physically significant to either increase supply or increase the potential for flooding. However, if the base water yield is in the range of 50 to 150 mm, then the same change in yield could be quite significant to down stream users. The important thing to keep in mind, is the instream or down stream water user. How will they be affected?

For example, consider a farm at the outlet of a hypothetical forested, northerly aspect watershed. The watershed is 100 km² in area and contains 80 km² of presently merchantable coniferous timber. The company holding the harvesting rights wants to harvest at a rate of 20 km² each year for four years in order to reduce the possibility of insect attack and/or fires in this holding. Coniferous regeneration is desired; however it may be necessary to use mechanical means to eliminate deciduous regeneration as it tend to occur naturally in most clear-cuts in this area. Average water yield from this watershed is 50 to 75 mm, average annual precipitation is 500 mm, and most of the runoff occurs during the spring freshet. The stream flowing through the farmers barn yard and near his out buildings overflows the banks about once every 25 year, or whenever the annual yield exceeds 100 mm. His house is built at a level so that it is only marginally affected by these 100 mm events. Considerable damage to his home would ocur if the annual yield exceeded 120 mm.

You are encouraged to change the year of harvest or the number of hectares harvested each year in order to meet the Alberta Environment's 15% of average annual yield criteria. See the scenario definition "Unnamed watershed above farm lands, two harvests" in the list of scenario names.

The first thing to do with WRNSFMF in this case would be to examine the effect of harvesting 20 km² in one year on average annual water yield. If this would produce no more than an annual increase of 20 mm at any time during its hydrologic life, then subsequent harvest can be evaluated. However, if this first harvest increases average annual yield by 30 to 50 mm, then subsequent harvests would only add to the problem created by the first cutting and do not need to be considered. What does need to be considered is "what intensity of harvest can be accommodated in one year without increasing the average annual yield to potential flooding levels".

Determining an annual yield base

This is site-specific data that probably wont be readily available. The approach that I use is to first determine if there is a stream gauge on the affected stream. If no stream gauge is available on your stream, look for one on a watershed of similar size, vegetation, topography and aspect in the vicinity. (Size, aspect and topography are the most important of these.) Examine the records of the selected watershed for high flow events, and the year that they occurred. Then talk to locals to determine if flooding has ever occurred, and if so, when and to what degree. Also, remember the in-stream users. Talk to fisheries biologists to determine if habitat is dependent upon stable stream flows or on periodic flooding events. Try to determine the actual water yields that are associated with suitable habitat maintenance. Compare

Personal communication, John Taggart, Alberta Department of the Environment, Edmonton, Alberta.

these local observations with those from the hydrographic record. If you are fortunate, you may find that several events have occurred, and that you can obtain a reasonable estimate of th number of mm of annual yield associated with those events.

If no records are available, then the Alberta Environment's15% criteria of average annual yield is a good start. It is based on the volume that can be added to unit hydrograph without an undue increase in peak flow. The average annual yield can usually be approximated from data from watersheds in the vicinity.

Percentage versus absolute yield changes

I feel that percentage changes are often misleading. Whenever possible, the absolute change in mm annual yield, or volume of water should be stated. For example, on some watersheds in Canada's northern forests, annual water yields in some years are very low, 0 to 50 mm, and a 30 to 40 mm increase in annual yield represents a huge percentage increase (60% to infinite), which would probably sound alarming to downstream users. However, these same watersheds generally have a great deal of internal storage so that very little change is often noted in outflow even with moderately high precipitation. In a case such as this, the percentage change in annual yield is misleading, as it implies a very large increase when little or no change in streamflow may be noted that year.

On the other hand, annual water yields from forested watersheds in the Rocky Mountains are generally on the order of 400 to 800 mm. These 30 to 40 mm increases would be quite low percentage-wise, but the volume of water they represent (3000 to 4000 cubic decameters from a 100 km^2 watershed) might still be of importance to downstream users, who might otherwise dismiss a change of 5 to 10 % as being too low to consider.

Estimating annual yield from unguaged watersheds

The WRENSS procedure was not designed to estimate annual yields for unguaged watersheds. Having said that, it may be useful in this context, and the calibration value obtained is a measure of how well the simulated data approximates the estimated actual water yield data. Calibration values of 0.85 to 1.15 indicate that the WRNSSDR procedure is giving a reasonably correct value for annual water yield.

The most important things to remember when applying it to this use is that WRENSS does not produce routed streamflow, it does not allow for carry over of surpluses or deficits from one year to the next, and it has no magic way to ensure that the precipitation data used to estimated that yield is either *accurate* or *representative* for the watershed in question. Neither is there any

See "Reliability of precipitation measurements", discussed in the Appendix.

Normally, the program looks for the name of a function in the "BA Func' and/or "TH Func" fields at run time. If a name is found then that function is used to calculate basal area and/or tree height regrowth in the clear-cut. However, if a value, rather than a name is entered, the basal area and/or height remains constant at that value. See example scenatios "Fire example, constant tree height" and "Conversion to agricultural crop". I have no idea whether the values for basal area and tree height used in this last example are reasonable, they are purely to illus-

guarantee that the water yield data it is being compared against is accurate, averaged over a sufficiently long period to negate the effects of internal storage on annual water yield, or representative of that unguaged watershed.

If precipitation data is representative, accurate and of sufficient duration, then the WRNSSDR program will provide an estimate of average annual water yield that is generally within 10 to 15 percent of measured (calibration values between 0.85 and 1.15). The important thing to remember, is that precipitation data is almost always an underestimate of actual and rarely representative of your area of interest!

Evaluating fires, insect, disease and other events.

Catastrophic events such as these often kill the trees, but leave them standing. This can be simulated in WRNSFMF by creating a clear-cut the size of the affected area, and by entering a constant in the "TH Func" field. What this does is create a clear-cut with ET loss as if the site was clear-cut, but with snow distribution and loss as for the uncut forest.

Similarly, one can simulate the effect of clearing in which no forest regrowth is expected, e.g., conversion to a pasture or other agricultural use. This is accomplished by forcing ET to some prescribed value based on a constant basal area, and by forcing height to a constant. The start and end year should be set to the same value in this situation because nothing changes with time.

FACTORS AFFECTING SIMULATION ACCURACY

A number of factors will affect the accuracy of the simulated water yield changes. The two most important of these are discussed below.

Climate data availability

Realistic and accurate climate data are necessary. The most critical data is precipitation. It is used to estimate potential evapotranspiration and water yield is obtained by subtracting evapotranspiration from precipitation. If the calibration option is selected in WRNSFMF, it will adjust any precipitation values that the user enters to make the water yield simulated equal that set for the watershed. This gives the appearance that any precipitation data can be used an still obtain accurate results. This is not the case. One should examine the calibration value. Good precipitation data, averaged over a 5 to 10 year period, properly corrected for gauge catch and elevation, should allow WRNSFMF to simulate the measured annual yield, averaged over the same time period, within ± 10 to 15 %, i.e., a calibration value between 0.85 and 1.15.

Availability of realistic regrowth data

This is a somewhat hidden problem. Regrowth data should be the easiest to obtain. However, most government agencies and companies do not keep regeneration surveys up to date, and even when they are, they will likely include data for merchantable species only. Data for the first few years after clear-cutting are the most critical, and the most likely to be missing because regeneration surveys generally start when the trees are of at least "breast height". This is changing as more information of an "environmental" nature is required, i.e., data on species suitable for wildlife cover and food, etc.

From the hydrologic standpoint, all vegetation growing on a site has implications on evapotranspiration and snow retention. Shrubs in particular have both height sufficient to affect snow loss and significant basal area to affect evapotranspiration. Yet, it is frequently impossible to obtain data on these from existing records because they are not considered commercially important. WRNSSDR users who have influence on inventory policy should attempt to have these data included in future regeneration surveys and databases.

APPENDIX

The USEPA WRENSS hydrologic procedure

The U.S. Environmental Protection Agency published a handbook entitled "Water Resources Evaluation of Non-Point Silvicultural Sources; A Procedural Handbook" (USEPA 1980) that contained graphical procedures for estimating the changes in water resources that could be expected following forest harvest. Chapter III of that handbook contained a set of procedures that one could use to estimate the water yield change associated with forest harvest. One set of procedures was intended for use in areas where the pattern of runoff (hydrograph) responded quickly to precipitation events throughout the year (Figure 21), and a second set of procedures for areas where the hydrograph displayed little or no response to precipitation during a winter season followed by a primary or dominant flow event during a snowmelt season (often

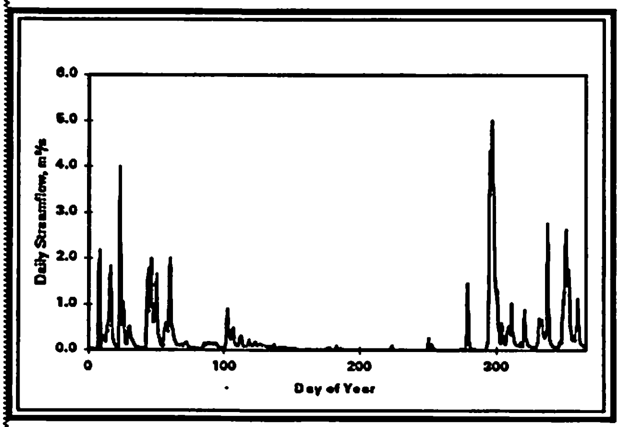


Figure 21. Example of a hydrograph from a region where rain is the dominant precipitation in terms of hydrologic response.

accompanied by significant rain) with secondary responses to summer precipitation events (Figure 22). The United States was divided into eight climatic regions (However hydrologic procedures were produced for only the first seven, the eighth being the Great Plains area that does not have commercial forests within it.) Figure 23. These regions have been extrapolated into Canada based on the forest associations dominant in each region (Figure 24).

The WRENSS graphical procedure was time-consuming to use and has apparently been little used in either the United States or Canada. Forestry Canada, Northern Forestry Centre, Edmonton, Alberta, produced a computer version for MS-DOS of the hydrological procedures, WRNSHYD ver. 1.0, which was distributed in 1989. Development and refinements to WRNSHYD ceased with ver. 1.1 in 1991, and it is no longer supported or supplied by Forestry Canada. WRNSHYD was written in Borland Turbo Pascal™ with a binary data format which is difficult to access except from within the actual program.

The MS-DOS WRNSHYD ver. 1.1 is still available free of charge, except for media and mailing costs, from RH Swanson & Associates, Canmore, Alberta, Canada (403) 678-6096.

My current development of computer versions of the WRENSS hydrologic procedures is toward interfacing its hydrologic routines with a database. These allows one to utilize input data from a variety of sources, such as a GIS, or to retain and easily edit input data from previous simulation runs. It also allows the results to be retained in a format suitable for further analysis or incorporation into the descriptive material accompanying an entity within a GIS.

The WRNSSDR version of the WRENSS hydrologic procedures, is a data-based implementation of the procedures for all *snow dominated region.* WRNSSDR is programmed within Microsoft ACCESS™ 2.0, with ACCESS carrying out most of the bookkeeping functions, and ACCESS BASIC the computational functions. WRNSSDR differs significantly from the snow dominated portion of the MS-DOS version, WRNSHYD, in that in addition to the database organization, regrowth can be incorporated as a function of clear-cut age so that time-sequences of water yield change as regrowth occurs, and the cumulative effects of varying ages of clear-cuts can be obtained. In contrast to the MS-DOS WRNSHYD, *WRNSSDR is entirely metric* with no provision for switching between English and metric units.

Curves for the deciduous "species" were only in the "New England" Region of WRENSS. These deciduous curves were included in all regions by Forestry Canada in their MS-DOS WRNSHYD version of WRENSS.

The SDR suffix of WRNSSDR is used to indicate that the procedure is applicable to snow dominated regions. I anticipate a similar suffix, RDR, for rain dominated regions if and when that version is produced.

In the text in this manual I refer to WRENSS when the hydrology portion of the original publication contains the information being cited or discussed, and these have not been modified for incorporation into the computer versions. I will use the acronyms for the computer versions (WRNSHYD, WRNSSDR, etc.) when referring to functions that have been added to, or modified from, the original WRENSS. Unless otherwise indicated, all mentions of functions or changes incorporated into WRNSSDR apply to the MS-DOS WRNSHYD as well.

WRNSFMF is a client-specific version with only those parameters for the two regions applicable to the Foothills Model Forest (FMF), Alberta, WRENSS regions "Rocky Mountains (4)" and "Continental/Maritime (6)" (Figure 24) incorporated within that program.

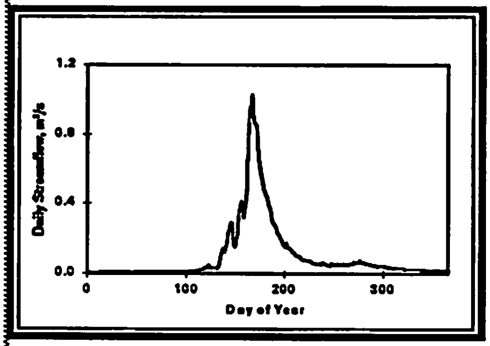


Figure 22. Example of a hydrograph from a region where snow dominates the hydrologic response.

WRNSDMI is similarly client-specific with only those parameters for the two regions applicable to the Daishowa-Marubeni International (DMI) forest management area of Alberta, WRENSS regions "New England (1)" (i.e., Boreal Forest) and "Rocky Mountains (4)".

Hydrology

The reader is referred to the WRENSS handbook for a fairly complete description of hydrologic processes and the way that they have been incorporated into the WRENSS procedure. Here, I present only a brief summary to highlight some of the more important aspects of hydrologic processes in forested areas. I include graphs of the functions used in WRENSS region "Rocky Mountains (4)" as representative of the functions derived for each region in the WRENSS handbook (USEPA 1980).

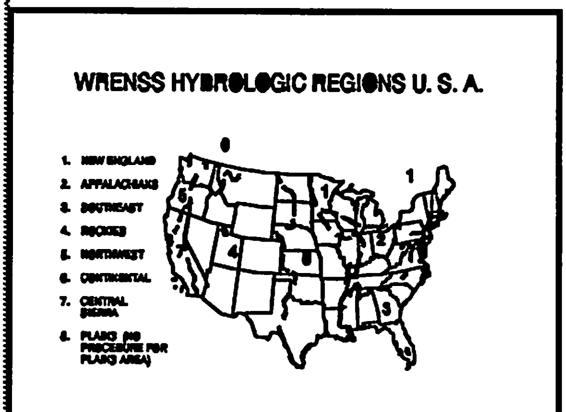


Figure 23. USEPA WRENSS regions as defined for the United States.

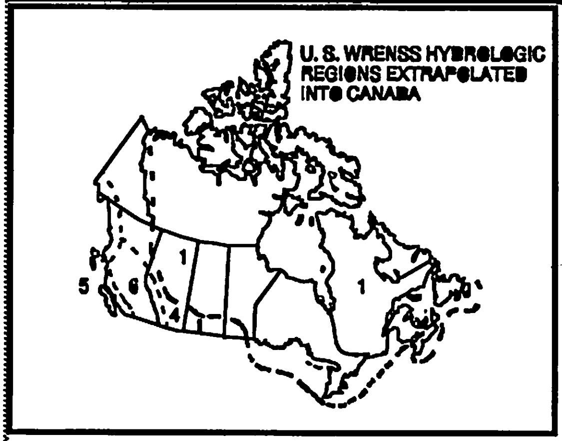
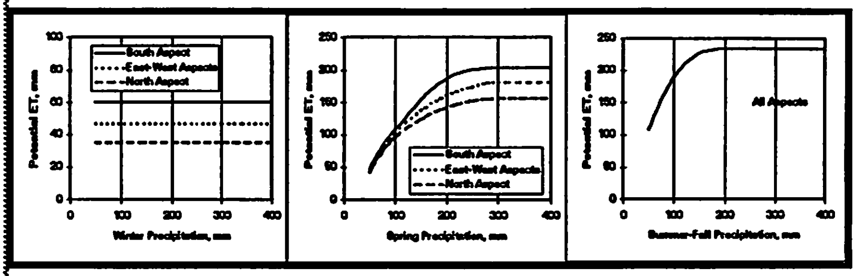


Figure 24. WRENSS regions as we have extrapolated them for use in Canada.

Basic forest hydrology in snow dominated areas

One of the principal features of the WRENSS procedure that sets it apart from most other hydrologic procedures or models is its incorporation of the areal distribution of snow as affected by spatially discontinuous forest harvest. Most have observed that snow accumulation in clearings is greater than under the uncut forest. There are three physical processes that are used to account for the greater amount of snow accumulated in the clearing versus the uncut forest: 1) lack of interception, 2) aerodynamic differences between clearings and treed edges, and 3) redistribution of snow initially caught in the canopy of trees adjacent to clearings. The last process has been questioned as to its validity and relative contribution (Troendle *et al* 1988). All of the routines in WRENSS that describe differential snow accumulation are based on empirical measurements of snow on the ground in clearings and under the canopy. They are therefore valid regardless of the process by which the differential accumulation occurred.

Figure 25. Seasonal potential evapotranspiration as a function of seasonal precipitation in WRENSS region "Rocky Mountains".



Potential evapotranspiration (PET)

Potential evapotranspiration (PET) is derived for the snow dominated regions of WRENSS as a function of local seasonal precipitation, Figure 25. At first glance this appears to be a rather crude way to derive this value. However, it makes sense in light of the complimentary relationship that appears to exist between atmospheric humidity and evapotranspiration (Morton 1971). And it is certainly one of the easiest and least data-intensive methods available to obtain PET.

Potential evapotranspiration is reasonably constant from year to year within a given climatic region. In WRENSS, it is variable only when precipitation is limiting. Annual values of PET for forested regions should rarely exceed 600 mm. In all of the WRENSS snow dominated regions, PET is either constant (Figure 25, winter) reaches a maximum value at a fairly low value for precipitation, and remains constant as precipitation increases above that value (Figure 25, spring and summer-fall).

Evapotranspiration (ET) from forests

Evapotranspiration is the combined quantity of evaporation and transpiration. Evaporation occurs from the canopy, understory vegetation, litter on the ground, and bare soil. Transpiration is water loss from the soil via the plants water conducting system, primarily via the stomata on the leaves, but also from the bark. Both evaporation and transpiration are primarily controlled by water availability and solar energy. However, a plant must be physiologically active for transpiration to occur and the seasonality of physiological activity is one of the fundamental differences between deciduous and coniferous forests. Both deciduous and coniferous trees lose some water from their stem, branch and leaf tissue during the winter. However, conifers can become physiologically active when the soil is still frozen and lose a considerable amount of water from the stem and leaves as the stomata open in response to favourable temperature and light regimes in the atmosphere. Deciduous trees don't generally resume physiological activity until the soil is unfrozen and has reached a temperature suitable for root growth to occur.

The relative importance of transpiration and evaporation

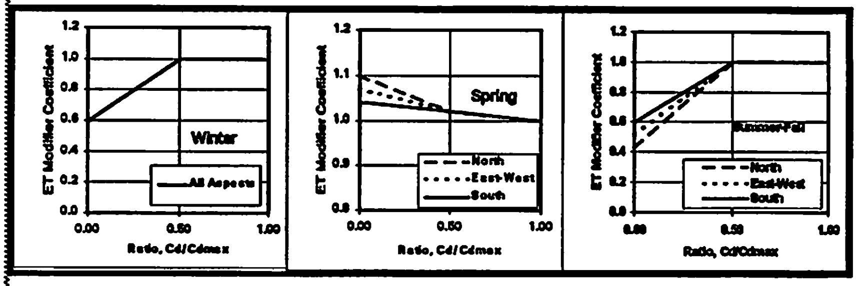


Figure 26. Modification to potential evapotranspiration from clear-cut blocks as a function of cover density reduction in WRENSS region "Rocky Mountains".

depends on the current state of the forest. In treed areas, transpiration will generally be greater than ½ of total ET. In cleared areas, evaporation may become the dominant process. Annual forest ET should generally be between 300 to 500 mm. In WRENSS, ET is considered equal to PET in fully treed forests. It is modified downward from PET upon clear-cutting, and increases toward PET as regrowth occurs, i.e., cover density (basal area) increases (Figure 26).

Forest modifications to spatial distribution of snow

In WRENSS, snow is distributed between treed and cleared areas as a function of clearing size. In WRNSSDR clearings smaller than 13 tree heights in the windward direction use an empirical relationship, derived from Alberta data, (Golding and Swanson 1978) between opening dimension and fraction of snow allocated to the clearing (Figure 27). In clearings where the windward dimension is greater than 13 tree heights, some rather

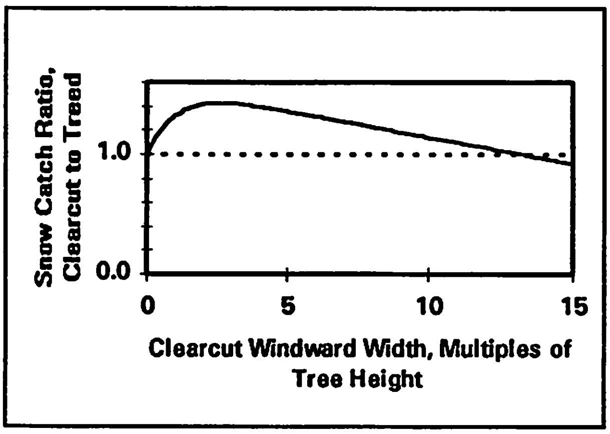


Figure 27. Differential distribution of snow between treed and cleared areas where the clear-cuts are ≤ 13 tree heights across.

complex equations are used which also account for sublimation of wind blown snow during transport within the clearing and the deposition of surviving snow particles into the downwind treed area (pages III.148 - III.152 *in* USEPA 1980, Tabler 1975).

Tabler (1975) provided the option of using a constant value for over-winter sublimation from the snow pack or simply ignoring it in his equations. I have exercised the option to ignore it within his equations and to compute it as a separate and optional routine, selectable as "Allow snow scouring" from the Global Options form (Figure 13). Sublimation is principally driven by vapour pressure deficit and wind speed. It is computed as an optional routine in WRNSSDR, applicable to the snow in all clearings, not just those greater than 13 tree heights across in the windward direction. The amount of sublimation that occurs during the winter is a function of the wind speed in an opening and the number of days that it does not snow during the winter. I assume that sublimation does not occur on days that it does snow because the vapour pressure difference between the snow surface and the atmosphere would be very small or zero.

Regrowth effects on ET

Regrowth affects evapotranspiration in WRENSS in two ways; a) through basal area increases which affect the cover density on a site, and b) through height growth which affects snow redistribution and loss in transport. In WRNSSDR, regrowth also affects the wind at the surface of a clearing and the subsequent opportunity for direct evaporation (sublimation) from the snow pack.

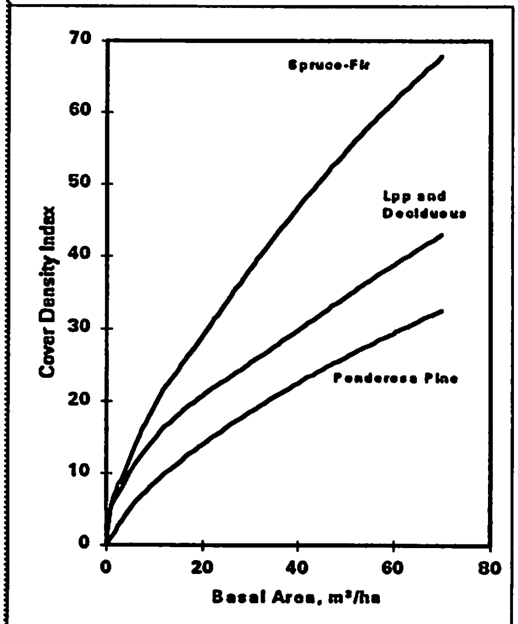


Figure 28. Cover density index as a function of basal area in WRENSS region "Rocky Mountains".

Base, stand and regeneration basal areas

Although the relationships affecting cover density and evapotranspiration are relatively well documented in the WRENSS handbook, some users appear uncertain of the terms used, e.g., C_{dmax}, C_{dact} and C_d, all of which refer to an *index to* cover density as a function of the basal area of a stand species in some silvicultural state (Figure 28).

The term C_d refers to the cover density of a treed site at its

The user does not interact directly with any of the cover density values because it is an index, not a measurable value. Rather than confusing the issue by using cover density terms for which there is no direct measure, I have referred to them in the WRNSSDR as measures of basal area, from which the various cover density terms are derived, Figure 26. The terms in WRNSSDR are "Stand basal area" (StandBA) from which C_d is derived, "Base basal area" (BaseBA) from which C_{dmax}, is derived and "Regenerating stand basal area" (RegenBA) from which C_{dact} is de-

present basal area. C_{dmax} refers to the maximum cover density that a given site may attain. It is considered in WRENSS as the cover density at which all available energy would be used in evapotranspiration, i.e., ET would equal PET for that site. C_{dact} is the cover density present after harvest.

I consider BaseBA to be a regional value for stands of that species on a given site class. BaseBA would therefore be the maximum expected basal area for a given site class. For example, the BaseBA for a hardwood stand in Alberta, site index 12 m at age 50, would be 28 m²/ha; that of the same species with site index 20 m at age 50, would be 44 m²/ha.

If the stand is a mature virgin stand, StandBA and BaseBA would probably be identical. However, the basal area of a second growth stand may never achieve BaseBA density because of management for a shorter rotation. In this case, the basal area expected at the end of the rotation period should be used for StandBA, BaseBA would still be that at maximum for the site.

Measure of effect

Regrowth effects on basal area are applied as modifiers to potential evapotranspiration. Each WRENSS region has a series of curves for each season and aspect. These take the form of a multiplier, generally between approximately 0.3 and 1.2 that is applied to PET to get the actual ET for the stand under the changed condition (Figure 28). The multiplier is a function of the actual or stand C_d divided by C_{dmax}. As an example, if the C_{dmax} found using Figure 26 was 50, and the C_{dact} was 10 (also from Figure 26) then one would enter Figure 28 with 0.2 to obtain an ET modifier coefficient of approximately 0.6 for the summer/fall season on a north aspect, i.e., ET would be 60% of PET. Note that if this modifier coefficient had been obtained for the spring season on the same north aspect that it would be greater than 1, i.e., approximately 1.08, for the same cover density fraction. *This is not a drafting or typographical error.* It implies that the surface of clearings on either north or south aspect may receive greater solar input after clear-cutting during some season of the year from re-radiation by the canopy on the south-facing treed edge on the north side of the clearing (Swanson 1988), and that ET would be *eight percent higher* from that clearing during that season than from the uncut forest. It is subtle changes in the energy balance of clearings such as this that make a general statement regarding the hydrologic effects of forest harvest impossible and the use of a model,

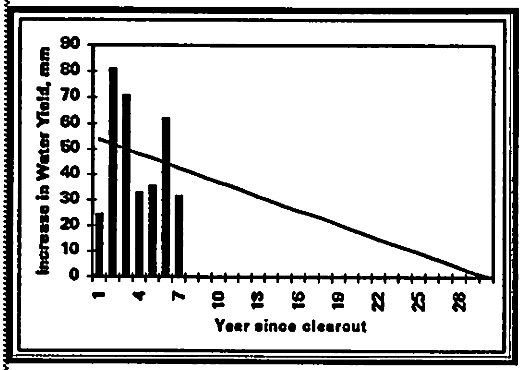


Figure 29. Decline in annual water yield from an aspen watershed after clearcutting. Unpublished analysis of data from the Streeter Experimental Basin, Alberta. Aspen forest was harvested in 1976 and water yield data colected through 1982 (Swanson et al 1986)

such as the WRENSS procedure mandatory.

Duration of effect

The duration of the effects of basal area reduction on evapotranspiration is directly related to the rate of regrowth. Figure 28 indicates that the ET modifier coefficient returns to approximately 1.0 for all seasons and aspects when the ratio of C_{dact}/C_{dmax} reaches 0.5. Regrowth data from the actual stand should be used of obtain a time trend of basal area increase if it is available. However, one can obtain a rough estimate with a linear relationship between age of clear-cut and age at maturity or rotation age, i.e., [(Age of clear-cut)/(Rotation age)](BaseBA). The effect of reduced basal area on ET will not completely vanish for about 30 years in Aspen stands (Figure 29) and 80 years in Spruce-Fir stands (Leaf and Brink 1975)

Regrowth effects on snow distribution

Height growth affects snow distribution in clearings with windward dimensions greater than 13 tree heights across. Slash and regeneration height is used in the snow loss equations to limit wind erosion from the snow surface. When the height of the regenerating trees is 1 ½ times the depth of the snowpack, no further erosion or transport of snow occurs. The WRNSSDR procedure calculates depth of the snow pack by assuming a snow density of 0.35.

In WRNSSDR, snow loss in transport is subtracted directly from the snowpack in a clearing. Snow transported from the clearings is deposited uniformly over the uncut portion of the watershed. These distributions reduce precipitation in clearings and increase it in the uncut portion of the watershed.

Duration of effect

The effects of regrowth on snow distribution are evident until the height of the trees in a clearing are equal to those of the surrounding stand. Regrowth data from the actual stand should be used of obtain a time trend of height increase if it is available. However, one can obtain a rough estimate with a linear relationship between age of clear-cut and age at maturity or rotation age, i.e., [(Age of clear-cut)/(Rotation age)](BaseTH). The effect of differential height on snow distribution will not completely vanish for about 30 years in Aspen stands (Figure 29, indicated only by the integrated effects of all ET parameters on water yield increase) and 120 years in Spruce-Fir stands (Leaf and Brink 1975)

Tree height was used in WRENSS only to define clear-cut size. Change in height was not incorporated as a variable in any of the graphical functions. In our computer versions, height is used to define the initial clear-cut size and height growth is used in the snow distribution and sublimation functions to limit their application through time as regrowth occurs. If height growth is not incorporated, clearings will continue to function as snow "traps" forever!

Water yield change versus water yield

The WRENSS hydrologic procedures were designed to estimate water yield *change*, not actual water yield. In order to estimate change, the procedure has to estimate water yields in an unchanged and changed state. Most users of WRENSS have looked at the yield estimated for the unchanged state and compared it with actual yield from the watershed. The two quantities are often quite different! This has caused some to lose confidence in the WRENSS procedures. Thus the question: How can changes in yield be reasonably accurate and actual yield not even in the same ball park? The answer lies in the constant nature of seasonal ET as compared to seasonal precipitation.

Evapotranspiration a constant?

Evapotranspiration is not constant from year to year, but it is more so than any other process in the hydrologic cycle. This is fairly well illustrated by the relationships between precipitation and potential evapotranspiration used in WRNESS (Figure 25). Evapotranspiration is a constant for the winter seasons and is relatively constant for all seasonal values of precipitation greater than 150 mm. Since the water yield in the uncut and cut state is simply the precipitation in those states minus their evapotranspiration, and since evapotranspiration is relatively constant over a broad range in precipitation, the simulated water yield in either state may be quite different from actual, but the difference between the simulated water yield in the two states will still reflect the correct magnitude of change.

Reliability of precipitation measurements

Precipitation is generally measured in some sort of container (precipitation gauge) at a site. The site may or may not be located physically near a watershed being examined. Precipitation is a "point" measurement in contrast to streamflow which integrates the effect of internal storage change and the difference between precipitation and evapotranspiration over a comparatively large watershed area. No matter how accurately one measures the precipitation that is caught in the container, if the water caught is not an accurate representation of actual precipitation, then the measure will not be either. Each of these precipitation-related factors, (amount caught in the gauge and the location of the gauge) influence the reliability of the precipitation data that is used in WRENSS or any other simulation modeling procedure.

The physical location of a precipitation gauge with respect to the watershed, is almost always a confounding factor. Precipitation gauges are often located near a stream gauge. The watershed for the stream is always higher than the stream gauge. Therefore, the precipitation will ordinarily have to be corrected for the difference in elevation between the gauge location and the watershed. This correction is called the *precipitation lapse rate*, and generally increases precipitation by some value per meter of elevation difference, for example, 0.001 mm/m.

The precipitation gauge may not even be near the watershed in question, or it may be situated in a place that receives more or less precipitation than the watershed, e.g., in a rain shadow. There is probably no reliable way to estimate the correction required in this case, other than adjusting total precipitation on a watershed until the measured and simulated annual water yield are equal. The WRNSSDR procedure allows one do this "adjustment" with the calibration option.

The quantity of precipitation caught relative to actual precipitation, is most important in windy sites and with snow precipitation. Goodison (1981)(Figure 20), compared the catch of various types of snow gauges in windy condition to that measured on the ground, and derived equations that can be used to "correct" the quantity measured in the gauge to equal that on the ground. Wind speed at the gauge is used to make this correction. Goodison's equations are available, as an option, for correcting winter season precipitation in WRNSSDR. No routines are available to correct for wind effects on rain.

Lastly, precipitation ought to be weighted over the watershed by elevation bands, and probably by aspects, if it is to be physically realistic. In most cases this is impossible because of lack of data specific to any elevation or aspect. Again, the calibration option in WRNSSDR can be used in lieu of weighting information.

The bottom line on the accuracy or reliability of precipitation is that some of the errors inherent in precipitation data are correctable while others are not. Unless one can make all of these corrections before precipitation data is used within WRNSSDR or any other simulation model, *one should not expect simulated annual water yield to equal actual.*

A final note

I don't want to end this manual until I have given you the answer to my question re: "Why is the yield negative with respect to the base year after cutting has ceased?" that was posed by the example where the base year is selected after some harvest has occurred. The answer is rather simple. The base water yield is higher than normal because it was based on an already harvested watershed. As regrowth occurs, the water yield from all harvests returns to pre-harvest levels, but the base yield is still set at the elevated rate from the prior harvest. Therefore, all of the normal water yield is negative with respect to the base yield value.

The above is the simple and correct answer to the question I posed in that example. However there is another instance when the water yields following harvest will be simulated as lower than the base yield. This occurs when regrowth of basal area has reached the approximately one half of Cdmax, and height growth has not reached the height of the surrounding stand. The model still treats the area as a clearcut because of the differential in tree heights between the clearcut area and the surrounding stand, but the cover density places the ET modifier at greater than 1.0. I don't know if this represents a real decrease in water yield or just an artifact of the WRENSS procedure.

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