Evaluating Changes in Annual Water Yield with Variations in Precipitation, Harvesting and Silvicultural Conditions

Typical Responses using WRNSFMF

prepared for

Foothills Model Forest
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I. Introduction & Background

In the 1970's the United States Department of Environmental Protection developed a process for evaluating water yield from non-point sources. An in-depth handbook was prepared. The methodology developed through that process became known as WRENSS (U.S. Environmental Protection Agency. 1980). Although the process was originally designed for regions of the United States, Swanson, R.H & Associates (1996) refined the procedures and modified the model for use in Alberta conditions. Swanson further developed computer versions of the model for use with Alberta hydrologic information.

Also in the 1970's a Canadian Forest Service research project (Swanson, R.H. and G.R. Hillman. 1977) was conducted to look at the change in water yield resulting from forest harvesting. Eighteen basins near Hinton Alberta were monitored for streamflow. A comparison was made of the average ice-free seasonal water yield from nine logged and nine unlogged basins.

Recently Foothills Model Forest (FMF) contracted Swanson, R.H. & Associates (1996) to develop a computer version of the WRENSS process. The model was customized for FMF so that it accepts database information and becomes a desktop computer tool for enhanced forest management planning. The WRNSFMF model is currently available for both Windows 3.1 and Windows 95.

FMF further requested, under this study, that testing of the model be conducted using watersheds in the FMF region. Streamflow measurements and background information from the Swanson, R.H. and G.R. Hillman (1977) study provided local hydrologic data. Additionally, local forest inventory and post harvest information for the study basins was provided by Weldwood of Canada Ltd..

This study was conducted using the WRNSFMF model (for Windows 3.1) - version 1.0a last modified 6 July 1996 (Swanson, R.H. & Associates 1996).

II. Objectives

There are four major objectives to be fulfilled in this study.

1) Conduct sensitivity analysis on WRNSFMF input parameters and compare results.
A sensitivity analysis will compare variables to identify those which cause the greatest change under typical water yield simulations. A matrix will clearly show the result of altering only one variable at a time. Hypothetical data will be tested in these simulations because they are easier to manipulate than real data. With hypothetical data it is easier to alter only variable and, therefore, demonstrate the result of one action as opposed to the interaction of many variables which may occur using real data.

The sensitivity analyses will evaluate area harvested, seasonal precipitation, cutblock size, cutblock aspect, wind speed, basal area, tree height, cover type, basin elevation and hydrologic region. Each primary variable will be adjusted up or down and simulated against a base level data set. A secondary variable will also be altered to gauge its interaction with the primary variable. The result of altering only one of the variables at a time will show how sensitive the variable is within the model.

2) Evaluate how the model responds to different land use options.
The sensitivity analysis will show some general trends as to how the model responds with different land use activities. These trends will be examined. For example, the model's sensitivity to harvesting small cutblocks as opposed to large cutblocks will be discussed.

Further to this evaluation, the sixteen basins used in the Swanson, R.H. and G.R. Hillman (1977) study will be evaluated taking into consideration the harvest that has occurred since 1974. These basins represented four working circles in the Weldwood Forest Management Agreement Area. The basins in each working circle will be combined to simulate water yield changes for each hydrologic region (Rocky Mountains and Continental Maritimes). Some general statements will be concluded regarding changes in water yield relative to changes in land use activity.

3) Evaluate how well the model estimates changes in water yield.
After a period of time in which water yield, climate, forest inventory and forest harvesting information have been gathered from a study area, water yield simulations can be compared with actual water yields. Historical data will be used to look at a predicted change in yield relative to a measured change. Data availability is limited for this comparison, however, further analysis of basin data from the Swanson, R.H. and G.R. Hillman (1977) study may provide an indication of how well the model estimates a real situation. A simulation with 1974 base flow data was conducted using an average date of harvest. This simulation provided a reasonably accurate estimate of water yield change. However, with actual harvest data available a further test will be conducted to compare the simulated result with the real measurement.

Additionally, logged and control basin pairs from the Swanson, R.H. and G.R. Hillman (1977) study, will be evaluated. In theory, one would expect that as area harvested increases so will yield changes increase. Thus, if the logged basins have more harvesting they should generate greater yield changes. This hypothesis will be tested using logged and control basin pairs.

4) Review data specifications for the model.
Preparing data and running simulations for the above objectives will provide ample opportunity to test the model and evaluate it's data requirements and ease of use. Recommendations will be made where changes may be required.

III. Data Requirements

Information needed to run simulations include topographic, hydrologic and climatic data, as well as, forest inventory data. Data may be real, hypothetical or a combination of the two. Regardless of whether the input data are real or hypothetical it should describe the following parameters.

A. Basin Parameters

Total basin area is required in square kilometers which is a measurement upstream from the basin outlet. Mean elevation should also be determined. Future model development will use the elevation variable to calculate a lapse rate. Elevation becomes a factor when the Continental Maritimes Region is used. The WRENSS procedure divided the continental United States into eight hydrologic regions to reflect differing ET rates. Only two of the regions (Rocky Mountains and Continental Maritimes) are applicable to the Foothills Model Forest and available for use in the model. The Rocky Mountains region is essentially geared to a snow dominated area while the Continental Maritimes region is both rain and snow. Knowledge concerning the location and physiographic features of the basin will help determine which region is the most appropriate for simulation.

B. Hydrologic Information

An annual water yield estimate is required for pre-harvest conditions. This estimate is used as a base flow in the model. Base flow is measured as an area yield (millimeters), that is, the total volume of water evenly distributed across the basin area. The base flow period must also be identified.

C. Climate Data

Climate data requirements include a measure of mean monthly precipitation in millimeters and a measure of the prevailing wind direction in kilometers per hour. Since part of the yearly precipitation is in the form of snow, these measurements must be as a snow-water-equivalent. The best information about hydrologic and climatic conditions should be obtained at the study location. However, if this is not possible, information from the nearest site with similar topographic and climatic conditions should be used as an alternative source.

D. Timber Inventory

Timber inventory is used to predict the effect of regrowth on evapotranspiration (ET) and surface wind speeds. The data may be constructed from a general knowledge of the study area or may be obtained from detailed stand level forest inventory. If local inventory is available then it should be used to generate more accurate results. Use of spatial inventory data which can be manipulated in a Geographical Information System (GIS) is recommended. Required components of the inventory include information about dominant tree species, their height in meters, their basal area in square metres and the area occupied in hectares. Age of the standing timber is not required as an input in the model, however it may be useful in estimating basal area.

In addition to the inventory of standing timber, it is necessary to have knowledge of harvest and silvicultural conditions, as well as growth dynamics. Harvest information may be obtained from harvest plans or from actual post harvest data. Harvest data requirements include tree species, date of harvest and area harvested. Spatial harvest information is recommended in order to maintain inventory detail and permit flexibility in developing harvest scenarios. Silvicultural information is required to provide knowledge about regeneration species. Growth dynamics information is necessary to estimate the maximum attainable height and basal area that can be expected from the regeneration stock.

IV. Data Description

A. Hypothetical Data

Data used for sensitivity analyses were hypothetical. Simulations were constructed with base level information as shown in Tables 1a to d. Single value modifications, except for basin size and base flow, were made for each simulation. For example, three block sizes were compared as a primary permutation against three levels of precipitation as a secondary permutation. The block sizes used were 1, 10, and 25 hectares. The precipitation levels were average, low and high. Average precipitation was based on actual long-term measurements from a site close to the Foothills Model Forest. Low values were developed by dividing each average measurement by two. High values were developed similarly by multiplying each average measurement by two. The low and high values appear to correspond reasonably well with actual extremes for the same site. Results from the simulations were recorded in a matrix to show which permutation had the greatest effect on maximum yield change.

B. Real Data

Real data were used to look at the impact of land use changes over time. Sixteen of the eighteen basins used by Swanson, R.H. and G.R. Hillman (1977) provided data for this component of the study. Prior to 1974 seven of the basins were unlogged and nine were logged. In 1995, the last year in which forest harvesting information was available for this study, only two were unlogged and several had had a second or third period of cutting. Harvesting has been conducted in varying amounts on each basin ranging from a low of 4% on Hendrickson catchment to 94% on Oldman-1 with an average of 46% harvesting across all the basins (Table 3). The basins range in size from 700 hectares to over 2500 hectares. The dominant tree species harvested from the basins was lodgepole pine (81%) with white spruce and black spruce approximately 13%. Deciduous harvest represented less than 1% overall. Other combinations of cover types amounted to approximately 5% overall.

Average daily streamflows from April 1 to September 15, 1972 to 1974 were available to determine annual water yields, however significant data gaps existed for 1972 and 1973. Therefore, only 1974 streamflow data were used to determine annual water yield. The average water yield in 1974 for the 18 catchments was 165 mm.

Historical climate data have been well documented by Swanson, R.H. and G.R. Hillman (1977), as well as in greater detail by Hillman, G.R., J.M. Powell, and R.L. Rothwell (1978). The Hillman *et al* report provides information on precipitation gauge measurements, basin elevations and general climate conditions.

The following assumptions were made regarding the use of real data.
1) Water yield from 1974 is used as a base flow determinant, however it is recognized that this flow may be higher than normal on some basins due to forest harvesting prior to the time of streamflow monitoring.
2) Precipitation values from Edson for the period 1970 to 1990 are assumed to be representative of the sixteen catchments.
3) Historical cutblock information is assumed to provide a reasonable identification of the tree species and tree heights surrounding the clearing.
4) 1984 Provincial Fully-Stocked Yield Tables, developed from the Phase 3 Inventory and reported in Alberta Forestry, Lands and Wildlife (1985), provide a reasonable estimate of basal area and height.

V. Expected Results

A. Sensitivity Analyses

A rating system has been developed specific to this study to categorize the expected and resultant sensitivities. The category rating is used for further discussion and summary purposes. Assumptions were made regarding the percent yield changes for the primary variable that would be considered high versus low. A 100% or greater change is assumed to represent a high sensitivity. Moderate sensitivity ranges from 25% to 99%. Low sensitivity ranges from zero to 24%. The low range corresponds reasonably well with Alberta Environment's 15% of average annual yield criteria which serves as benchmark for low yield changes (Swanson, R.H. & Associates 1996). This is considered to be the volume that can be added to a unit hydrograph without significantly affecting peak flows.

The model is expected to be highly sensitive to area cut, block size and regeneration species. The standing forest transpires large volumes of water from the soil. As the standing forest is reduced one would expect additional water to be available for streamflow and therefore higher yield changes. Conversely, when the total area harvested is small the change in yield will be negligible.

It has been documented that block size is an important element for capturing snow. Clearings of approximately 2 to 3 tree heights in the windward direction will maximize snow accumulation (Swanson, R.H. & Associates 1996). Therefore, simulations with small cutblock sizes will be expected to show high yield changes while large cutblocks will show minimal yield changes.

Moderately sensitive parameters should include block aspect and basal area. Block aspect and growth parameters influence ET. WRENSS curves (U.S. Environmental Protection Agency 1980), defined by cover density ratios and ET modifier coefficients, indicate that ET will have the most influence on yield changes when cover densities are less than half of maximum potential cover density. In other words when the regenerated tree cover is young and represents less than one half of its potential basal area growth, then ET will be low. Therefore, water yield increases should be significant in these early stages. After this point ET will have greater influence and consequently reduce yields. Deciduous cover types may reach this 0.5 ratio sooner than coniferous types and therefore reduce the longevity of the yield effect. However, judging from the slope of the ET modifier curves for the Rocky Mountains region (U.S. Environmental Protection Agency 1980) it appears that ET changes will be moderate and therefore sensitivity to aspect and basal area will also be moderate.

Wind speed influences snow interception, distribution and loss through sublimation. Exposed cutblocks greater than 13 tree heights in the windward direction when subjected to wind may loose snow into the adjacent standing timber (Swanson, R.H. & Associates 1996). Moderate sensitivity to wind speed and tree height will be expected.

Elevation should be moderately sensitive to change. Elevation does not influence yield in the Rocky Mountains region, however, in the Continental Maritimes elevation is a factor in changing yields.

The effect of hydrologic region on yield sensitivity is probably low. Simulations tend to produce 20 percent higher yields for the Rocky Mountains region (pers com R.H. Swanson) versus the Continental Maritimes.

Low sensitivity would be expected with normal precipitation levels. Swanson, R.H. & Associates (1996) discuss how precipitation becomes a limiting factor for potential evapotranspiration (PET) only when spring and summer/fall precipitation is low. PET curves indicate that total annual precipitation levels must be below 200 mm in the Rocky Mountains region for precipitation to be very sensitive to change. Precipitation at this level (less than 200 mm) rarely occurs in FMF, therefore, sensitivity at a normal precipitation level (400-500 mm) would be low.

B. Responses to Changing Land Use Activities

Experimental watershed studies have shown that water yield increases in the order of 20 to 30% are possible for snow/rain and snow dominated regions (Swanson, R.H. and G.R. Hillman 1977). It is expected that similar yield increases will be noted from simulations using the sixteen catchments referred to previously. Smaller changes may also be noted because of forest inventory changes since the 1974 study. For example, new inventory since 1974 may change what was a clear cut in 1974 to advanced regeneration in 1990. Therefore the change in simulated yields may be lower because the regenerated forest is transpiring more than the cutblock areas.

Additionally, previous simulations on these basins were conducted when total harvests were less and the period of harvesting encompassed only one or two passes. On some basins a third pass has occurred. The duration of yield increases will probably be extended due to this third pass harvesting. However, the maximum yield increase will not change, since the harvesting occurs in periods rather than continuously.

VI. Results

A. Sensitivity Results using Hypothetical Data

Tables 1a to d show the sensitivity analyses results (maximum yield increase in millimeters). These matrices do not encompass all the permutations. They do, however, look at all the important primary and secondary variables that interact in the model. Some of these variables can be altered through user screens (e.g., region) while others are adjusted by manipulating the database (e.g., regeneration cover types, cutblock sizes).

1. Area Cut

Table 1a displays primary variables directly associated with harvesting - total area cut and cutblock size. Total area cut was altered from 25 percent of the total basin area, to 50 and 75 percent respectively. Maximum yield increase changed dramatically as the area cut increased (i.e., a 100% greater change in yield from 25% to 50% forest cover removal and almost 200% greater change from 25% to 75% removal). This change was evident in the test of both secondary parameters - block size and regeneration species. Maximum yield changes occurred with alterations in the secondary variable, but not with the same magnitude of change as the primary variable (area cut). The effect of forest cover removal results in a reduction in ET. The model is highly sensitive to total area harvested.

Table 1a. WRNSFMF Sensitivity Analysis

Base Level Information	Value	Primary Variable	Secondary Variable (yield changes shown in millimeters)		
basin size (km^2)	10		Block Size		
base flow (mm)	135	Area Cut	1 ha	10 ha	25 ha
precipitation (mm)	569	25%	21.4	13.7	3.9
precipitation gauge	Nipher	50%	42.9	27.5	7.8
surrounding species	Lodgepole	75%	62.9	41.2	11.7
surrounding BA (m^2)	40				
surrounding TH (m)	25				
block aspect	North				
block size (ha)	10		Regeneration Species		
harvest % of basin	50		Spruce-Fir	Lodgepole Pine	Deciduous
regeneration species	Lodgepole	25%	13.7	13.7	13.7
wind speed (km/hr)	7.9	50%	27.5	27.5	27.5
wind direction	West	75%	41.2	41.2	41.2
basal area (m^2)	0		Precipitation		
tree height (m)	0	Block Size	average	low	high
yrs to max basal area	80	1 ha	42.9	42.9	42.9
yrs to max tree ht.	120	10 ha	27.5	27.5	27.5
region	C.M.	25 ha	7.8	7.8	7.8
simulation period (years)	1				

2. Block Size

Table 1a also shows that block size is a highly sensitive variable and can have a significant impact on yield. A change in block size from one hectare to 25 hectares caused a 35 mm reduction in maximum yield. Block size was tested against precipitation levels, however no change resulted from altering the secondary variable. Yields are impacted by the spatial distribution of snow. In particular, snow is maximized in the smaller blocks leading to higher simulated yields. Clearings with windward lengths of more than 13 tree heights are subject to wind erosion, potential loss of snow through sublimation and transport, and snow redistribution into the uncut forest (U.S. Environmental Protection Agency 1980). A one hectare block is approximately equal to four tree heights assuming the trees are 25 metres in height. If block size is 25 hectares or greater then it's tree height equivalent is about 20. This exceeds the distance for improved snow capture and leads to snow loss.

3. Seasonal Precipitation

Table 1b verifies that altering seasonal precipitation has little impact upon yield changes. Although there are small differences between yield simulations, the magnitude of difference was minimal compared with area cut and block size. Low and high precipitation levels showed some yield differences between seasons, however the difference was small. It appears that precipitation has to be lowered further than the tested values before significant differences would occur between seasons. It can be concluded that the model is not sensitive to seasonal changes in precipitation or changes in precipitation levels when the levels are within normal ranges.

Table 1b. WRNSFMF Sensitivity Analysis

Base Level Information	Value	Primary Variable	Secondary Variable (yield changes shown in millimeters)		
basin size (km^2)	10		Precipitation		
base flow (mm)	135	Seasonal Precipitation	average	low	high
precipitation (mm)	569	Winter	27.5	28.5	25.5
precipitation gauge	Nipher	Spring	27.5	27.8	25.0
surrounding species	Lodgepole	Summer/Fall	27.5	22.6	27.6
surrounding BA (m^2)	40				
surrounding TH (m)	25				
block aspect	North				
block size (ha)	10		Precipitation		
harvest % of basin	50	Aspect	average	low	high
regeneration species	Lodgepole	North	27.5	27.5	27.5
wind speed (km/hr)	7.9	East/West	40.0	40.0	40.0
wind direction	West	South	55.4	55.4	55.4
basal area (m^2)	0		Block Size		
tree height (m)	0		1 ha	10 ha	25 ha
yrs to max basal area	80	North	42.9	27.5	18.1
yrs to max tree ht.	120	East/West	59.7	40.0	21.1
region	C.M.	South	79.6	55.4	35.6
simulation period (years)	1		Block Size		
		Wind Speed	1 ha	10 ha	25 ha
		0 km/hr	52.6	50.7	50.6
		5 km/hr	46.5	36.0	23.4
		10 km/hr	40.3	21.3	-0.6

During the summer ET (from the standing forest) is a major source of water loss from the catchment, however this loss does not generally exceed 600 mm annually (Swanson, R.H. & Associates 1996). Additionally, ET remains constant after a certain level of precipitation has been reached. Even low precipitation levels usually provide more water in the system than the forest can remove through ET. It appears that yield changes increase slightly as precipitation levels become more extreme. For example, low winter precipitation generates greater yield changes than when summer precipitation is low.

4. Aspect

Contrary to the expected result, aspect is a highly sensitive variable in the model. Approximately a two fold increase in yield occurred when cut blocks were altered from north to south. The yield values did not change when aspect was tested against the secondary variable precipitation. However, the yield values did vary with changes in block size. Larger blocks generated smaller changes in yield for all aspects. Tree removal from south aspects has the greatest potential to generate high yield changes.

5. Wind Speed

Wind speed has an effect on yield changes, however, it is also influenced by factors such as block size. Table 1b shows that changes to wind speed on small cutblocks produce minimal yield changes, where as, on large cutblocks the yield changes are extreme.

6. Basal Area

Table 1c shows the effect of changing growth parameters such as basal area and tree height. Basal area is a moderately sensitive variable. When basal area was modified from zero to one square metre, the maximum yield changes across regeneration species were reduced 37%, 61% and 66% respectively. At zero basal area there is no difference between species. However, as basal area increases the spruce-fir regeneration generates higher yield changes than lodgepole pine or deciduous types. The difference in yields between species is probably a reflection of their physiological differences (i.e., the high growth rate and transpiration of lodgepole pine and deciduous versus the lower transpiration rate of spruce-fir).

Table 1c. WRNSFMF Sensitivity Analysis

Base Level Information	Value	Primary Variable	Secondary Variable (yield changes shown in millimeters)		
basin size (km^2)	10		Regeneration Species		
base flow (mm)	135	Basal Area	Spruce-Fir	Lodgepole Pine	Deciduous
precipitation (mm)	569	0 m^2	27.5	27.5	27.5
precipitation gauge	Nipher	1 m^2	17.2	10.7	9.2
surrounding species	Lodgepole	2 m^2	11.9	4.1	4.1
surrounding BA (m^2)	40				
surrounding TH (m)	25				
block aspect	North				
block size (ha)	10		Regeneration Species		
harvest % of basin	50	Tree Height	Spruce-Fir	Lodgepole Pine	Deciduous
regeneration species	Lodgepole	0 m	27.5	27.5	27.5
wind speed (km/hr)	7.9	1 m	50.8	50.8	50.8
wind direction	West				
basal area (m^2)	0	40 yr simulation	Regeneration Species		
tree height (m)	0	Cover Type	Spruce-Fir	Lodgepole Pine	Deciduous
yrs to max basal area	80	Brush & Muskeg	45.4	45.4	45.4
yrs to max tree ht.	120	Commercial Timber	44.1	27.5	29.3
region	C.M.				
simulation period (years)	1				

7. Tree Height

Tree heights also influence yield changes, particularly when the tree is in its early stages of growth. As tree height was raised from zero to one metre the yield changes were increased by 85% for all species. Tree height is a moderately sensitive variable in the initial stage of tree growth.

8. Cover Type

If one were able to convert an area from brush and muskeg to a commercial forest then a reduction in yield would occur. The yield is lowest when the area is regenerated to pine or deciduous cover. This difference between species is a reflection of their ET rates. Changing cover types on sites not currently supporting commercial timber to a spruce-fir commercial forest generates a change that is low in sensitivity. Conversion to a lodgepole pine or deciduous commercial forest generates a change that is a moderately sensitive change.

9. Elevation

Table 1d shows the effect of changes to elevation and hydrologic region. Elevation is a factor in simulations when the Continental Maritimes region is used. Significant yield changes occur at elevations of 1220 metres. Results show that a yield change increased 60% at elevations greater than 1220 metres. This change reflects moderate sensitivity. Further yield responses to elevation are unchanged as precipitation levels, as a secondary variable, are modified.

Table 1d. WRNSFMF Sensitivity Analysis

Base Level Information	Value	Primary Variable	Secondary Variable (yield changes shown in millimeters)		
basin size (km^2)	10		Precipitation		
base flow (mm)	135	Elevation (CM)	average	low	high
precipitation (mm)	569	< 1220 m	16.6	16.6	16.6
precipitation gauge	Nipher	> 1220 m	27.5	27.5	27.5
surrounding species	Lodgepole				
surrounding BA (m^2)	40				
surrounding TH (m)	25				
block aspect	North		Precipitation		
block size (ha)	10	Region	average	low	high
harvest % of basin	50	Rocky Mountains	45.4	45.4	45.4
regeneration species	Lodgepole	Continental Maritimes	27.5	27.5	27.5
wind speed (km/hr)	7.9		Aspect		
wind direction	West	Region	North	East/West	South
basal area (m^2)	0	Rocky Mountains	45.4	40.1	34.7
tree height (m)	0	Continental Maritimes	27.5	40.0	55.4
yrs to max basal area	80				
yrs to max tree ht.	120				
region	C.M.				
simulation period (years)	1				

10. Hydrologic Region

Hydrologic region as a variable is moderately sensitive. Using hypothetical data the simulated yield change for the Continental Maritimes region is 39% lower than the Rocky Mountains region. However, further analysis using real data from the sixteen catchments used in the Swanson, R.H. and G.R. Hillman (1977) study showed no definite trend that the Continental Maritimes region generates lower yield changes. Appendix I shows these results. Swanson, R.H. and Associates (1996) indicate that both regions are appropriate for the FMF area. It is advisable, therefore, to test simulations with both regions to obtain a range of yield values. If one's objective is to maximize yield then one could use the lower value as a conservative estimate of expected yield change.

B. Summary of Sensitivity Results

Table 2 summarizes the degree of sensitivity to change for each variable. It is interesting to note that the variables subject to the greatest sensitivity (area cut, block size and aspect) are those which can be managed through forest harvesting practices. Other manageable variables, but with less sensitivity (i.e., moderate and low) include basal area, tree height and cover type. Those variables which cannot be managed on a site specific basis include seasonal precipitation, wind speed, elevation and hydrologic region.

Table 2. Sensitivity Results Summary

Variable	High	Moderate	Low
Area Cut	•		
Block Size	•		
Season			•
Aspect	•		
Wind Speed (small cutblock)			•
Wind Speed (large cutblock)	•		
Basal Area		•	
Tree Height		•	
Cover Type (Spruce-Fir)			•
Cover Type (Pine/Deciduous)		•	
Elevation		•	
Region		•	

C. How have water yield changes been influenced by land use activities?

There are both natural and human elements which influence the degree of water yield changes. The natural element depends upon basin response characteristics such as soils and water storage capacities. For example, insignificant yield responses may be due to extensive areas of muskeg and permeable soils. On the other hand, a basin can be flashy and exhibit high peak flows due to its steep terrain. The human element deals with people's concept of change. Increased yields from forest harvesting may seem insignificant to a forester planning wood supply to a local mill. However, to some downstream users the increased yield may be thought of as beneficial because it could alleviate water supply problems. To others it may seem like an increased potential for flooding. Water storage capacities, peak flows, water supply and flooding are issues that have been discussed in many studies. Further discussion in this study, however, deals only with annual water yield changes resulting from land use activities.

The study basins used by Swanson, R.H. and G.R. Hillman (1977) provide an example of how water yields have changed as a result of land use activities - specifically forest harvesting. Table 3 summarizes the yield changes simulated for individual basins and for combined basins within working circle categories. Figures 1 to 8 depict the simulated yield changes from the year prior to the first harvest until the effects on yield are reduced.

Table 3. Maximum Yield Increases for Study Basins in the FMF Region

Simulated using mean monthly precipitation values for Edson 1970 to 1990

Basin Name	Size	Area Cut		Base	Continental Maritimes		Rocky Mountains	
	ha	ha	%	mm	mm	%	mm	%
Oldman-2	1700	574	34%	77.6	20.3	26.2	25.0	32.2
Oldman-3	1490	475	32%	155.3	14.5	9.3	15.4	9.9
Oldman-1	1640	1539	94%	137.3	27.3	19.9	42.2	30.7
Fish *	2560	1792	70%	101.1	19.0	18.8	17.8	17.6
Oldman-4	1970	796	40%	202.7	12.5	6.2	14.2	7.0
Athabasca Working Circle	**9360**	**5176**	**55%**	**133.3**	**10.1**	**7.6**	**13.0**	**9.8**
Pine-2	2390	289	12%	198.5	4.6	2.3	4.3	2.2
Pine-1	2210	1290	58%	296.9	18.6	6.3	18.6	6.3
Edson R. -5	700	383	55%	271.4	24.9	9.2	20.9	7.7
Edson R. -4	2310	1152	50%	266.0	21.4	8.1	18.5	6.9
Marlboro Working Circle	**7610**	**3114**	**41%**	**254.4**	**10.8**	**4.2**	**10.8**	**4.3**
Hendrickson	2200	94	4%	129.2	4.1	3.2	3.0	2.3
Fox-2	1820	1133	62%	102.2	21.2	20.7	20.0	19.6
Fox-1	1230	834	68%	132.9	23.5	17.7	29.5	22.2
Berland Working Circle	**5250**	**2061**	**39%**	**121.4**	**10.2**	**8.4**	**13.9**	**11.4**
Anderson-2	1970	759	39%	107.9	14.7	13.7	20.7	19.2
Unnamed-2	880	248	28%	86.8	7.9	9.1	10.2	11.7
Anderson-1	1070	600	56%	205.9	28.0	13.6	27.3	13.3
Quigley	1680	803	48%	192.0	22.6	11.8	19.9	10.4
McLeod Working Circle	**5600**	**2410**	**43%**	**148.1**	**12.3**	**8.3**	**12.4**	**8.3**

* Fish Creek may be a different tributary than the study basin referred to as Fish Creek in the Swanson, R.H. and G.R. Hillman (1977) study.

The results from simulations of these sixteen watersheds do not show the magnitude of yield increase that were expected for individual basins. Only two basins in the Athabasca Working Circle and two basins in the Berland Working Circle show maximum yield increases between 20 and 30 percent. A number of factors come into play when using real data and it is difficult to determine which variables are responsible for limiting the increases. Possible explanations for the lower than expected yields, according to R.H. Swanson pers com, is that earlier measurements by Swanson, R.H. and G.R. Hillman (1977) produced more water than was possible to simulate. This was due to the use of an average year of harvest in the 1960's. Actual post harvest data were not used in 1977, however, a significant amount of harvesting had occurred before 1960. Additionally, re-growth curves used in these simulations may be accounting for faster regeneration than previously simulated.

Climate data, such as wind speed, can influence the simulations as shown previously in the sensitivity analysis. These simulations were run using 5.0 km/hr wind speeds. However, simulations were also run at 7.9 km/hr and for all catchments the yield changes were reduced using higher wind speeds. The type of precipitation gauge also influences the yield change. Several gauge types are available to choose from in the model and each one is corrected differently for wind speed. The Nipher gauge, used at Edson airport, has a small correction for wind while the unshielded and Alter type gauges, used in the Swanson, R.H. and G.R. Hillman (1977) study receive a large correction for wind.

Out of the sixteen individual basins, the maximum predicted yield increase occurred on Oldman-1 catchment with 94% of its area harvested. Harvesting on this basin occurred continuously over a 20 year period and the result on water yield was an estimated 42 mm maximum increase. This translates into approximately 65,000 cubic decameters of additional runoff for the year in which the maximum occurred. Over the 40 year simulation period the total increased yield is in the order of 900,000 cubic decameters. Put into perspective this is a volume of water one kilometer square and nine meters deep (similar to a small foothills lake).

Maximum yield increases simulated with the Continental Maritimes range from a low of 10.1 mm in the Athabasca working circle to a high of 12.3 mm in the McLeod working circle. These yield increase levels are probably realistic, considering that the total harvested area under these combined working circle simulations ranged from only 39 to 55 percent. Higher yields would have occurred with increased harvesting.

In terms of yield responses due to land use activity, Figures 1 to 8 illustrate how the yield has been impacted. The graphs for each working circle show how water yield changes have responded to periods of harvesting. In each working circle a significant amount of the total harvest occurred throughout the 1960's and 1970's. This is evident from the graph peaks during these periods. The Rocky Mountains region simulated higher yields in two of the four working circles. The Rocky Mountain region produced maximum yields at 29 and 12 percent higher than the Continental Maritimes region for the Athabasca and Berland working circles respectively. The maximum yields were the same between regions in the Marlboro and McLeod working circles. The differences in yield increases are evident by looking at the shape of the graphs. The peak on the Rocky Mountains curves are generally higher. The Rocky Mountains region also simulates a more rapid and dramatic response over time. The slope of the Rocky Mountains curve is steeper, particularly on the decay portion of the curve.

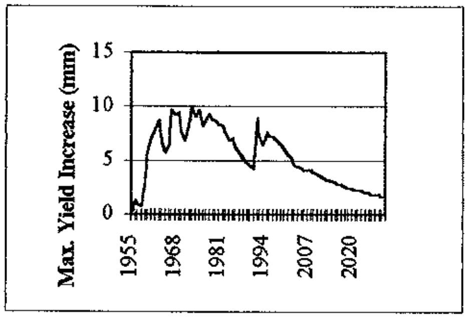

Figure 1 Athabasca WC - Continental Maritimes

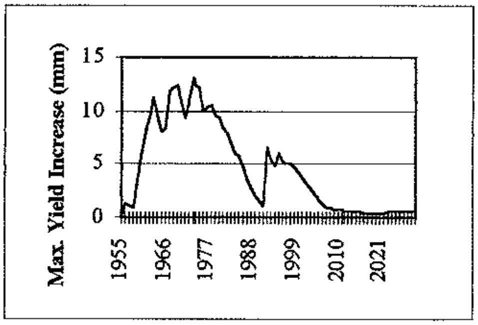

Figure 2 Athabasca WC - Rocky Mountains

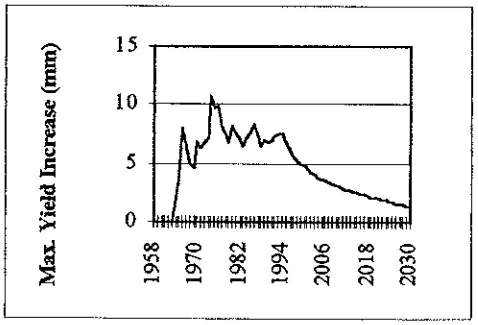

Figure 3 Marlboro WC - Continental Maritimes

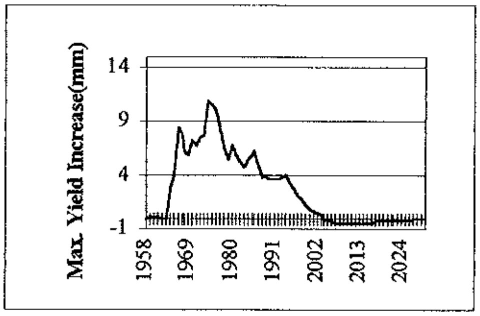

Figure 4 Marlboro WC - Rocky Mountains

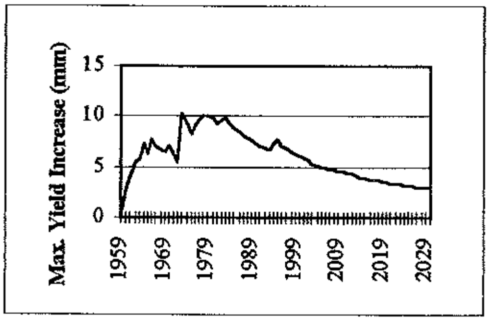

Figure 5 Berland WC - Continental Maritimes

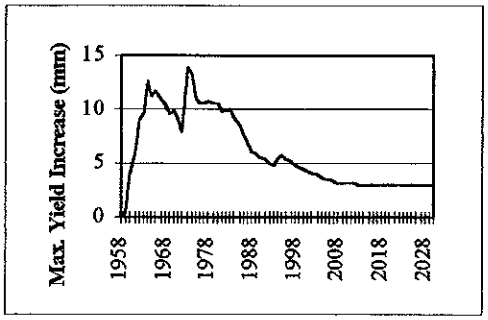

Figure 6 Berland WC - Rocky Mountains

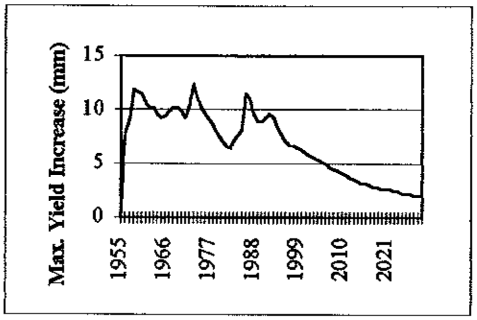

Figure 7 McLeod WC - Continental Maritimes

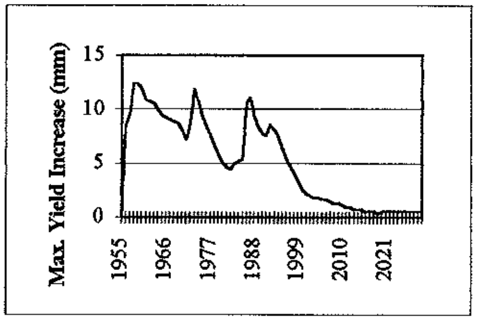

Figure 8 McLeod WC - Rocky Mountains

The relationship of harvesting periods to changes in yield can also be seen in Figures 9 and 10. Figure 9 shows a relatively continuous harvest for about 20 years. A change in yield follows quickly after the first year of harvesting and continues to increase for the duration of the 20 year harvesting period. Once the major cutting periods have ceased then the yield dissipates quite rapidly. Figure 10 shows a basin response with less intense cutting periods. The yield curve shows less dramatic changes from year to year and the overall response is drawn out for a longer period of time (i.e., the water yield decay continues for 10 to 20 years longer than the basin in Figure 9.) This differing response is due to the ET curves. The Continental Maritimes region shows the effect of ET until cover density is at maximum. The Rocky Mountains region shows the effect of ET until cover density is one half of maximum. These responses show the significance of the intensity of harvest on water yield.

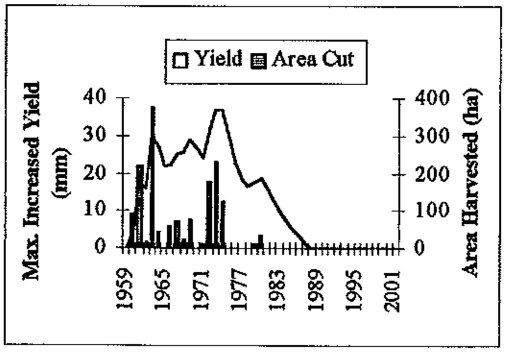

Figure 9 Generated Yield in Response to Intensive Harvest (Oldman-1)

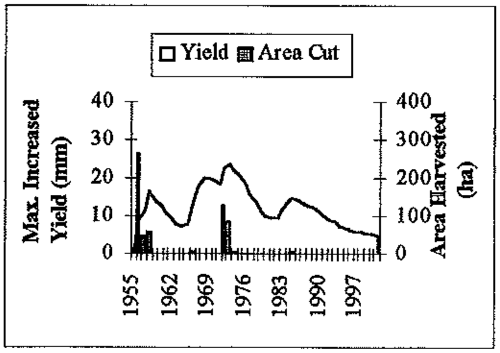

Figure 10 Generated Yield in Response to Non-Intensive Harvest (Anderson-1)

The combined simulation of harvesting sixteen basins produces a maximum yield increase of 6.4% (Figure 11). The graph indicates how the peaks in yield correspond with peaks in harvesting. Additionally, the graph shows the long-term effects which continue for more than 20 years after harvesting ends.

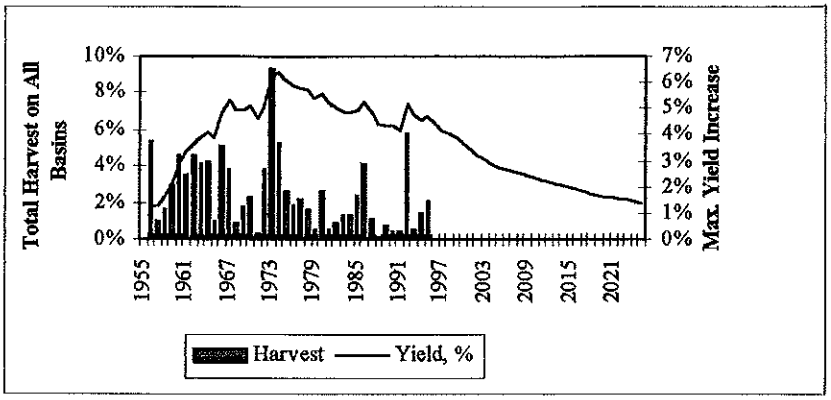

Figure 11 Yield Response to Combined Harvest on Sixteen Basins

D. How well does WRNSFMF estimate changes in water yield?

This is a difficult question to address with the limited data used in this study. Perhaps the best answer would be obtained from a study where numerous basins were gauged before and after treatment. Each basin would be gauged prior to harvesting to establish a base flow for yield estimation and then gauged after treatment to compare with the predicted yield from the model. In lieu of such data one can look at yields from basins that were paired by Swanson, R.H. and G.R. Hillman (1977). These basins were grouped according to similar topographic and climatic conditions and were assumed to be equal in flow prior to treatment. Figure 12 compares the yield increases between the logged basins and the controls for 1974.

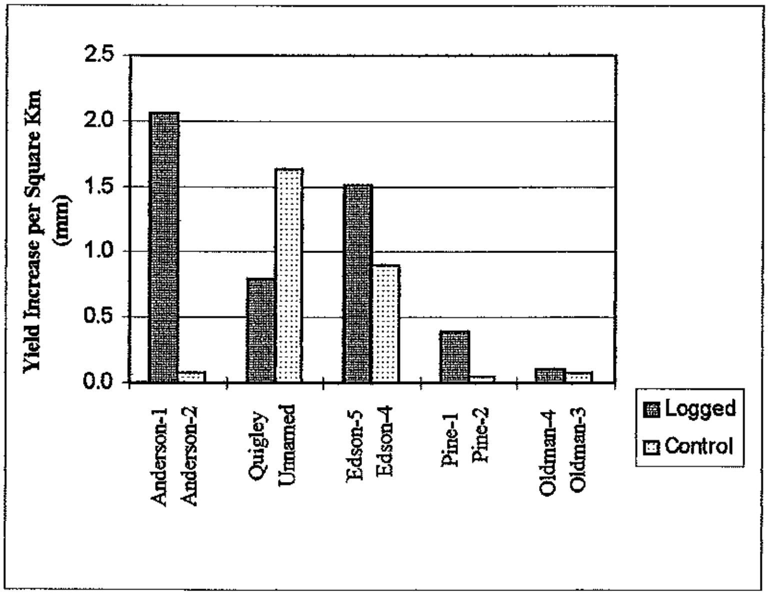

Figure 12 Comparison of Yields for 1974 from Paired Basins

Four of the five logged basins show greater yield increases than the control basins, even though the magnitude of difference is not the same from one grouping to the next. This difference could be related to a number of factors such as soil moisture storage conditions, amount of harvested area, type of harvesting and general basin response characteristics. These factors are not addressed by this comparison. Simulations in this study showed that yield increases were greater with increasing harvested area.
In 1974 the logged basins had been harvested significantly more than the control basins. In light of this knowledge one would expect the model to predict larger yield increases for the logged basins. Figure 12 confirms this with the exception of the Quigley/Unnamed basin pair. This exception may be due to basin response characteristics and intensity of harvest.

Similarly, a logged and a control basin can be used to examine how the model works in a real situation. Oldman-1 (logged) and Oldman-2 (control) basins have similar basin characteristics. They were paired in the Swanson, R.H. and G.R. Hillman (1977) study to look at the change in yield after harvesting. If their basin characteristics are similar then using the base flow from the control should provide a reasonable starting point for simulating the change in yield on the logged basin. Since actual measurements are available from the logged for 1974, this may show whether or not the model simulations are within reasonable limits.

Oldman-1 was logged approximately 84% by 1974 and 94% by 1995. The sensitivity analysis showed that area harvested had a significant impact on yield changes. A 70% increase in yield occurred when the total area cut was 75% of the basin. One might expect a similar increase to be simulated in this example too, however, since this is a real situation the interaction of many variables should be considered (i.e., block size, aspect, site growth factors, precipitation, etc.). This interaction may lower the potential increase. In 1974, base flow from the control was measured at 77.5 mm. A 70% increase in yield would estimate the yield to be 132 mm.

Precipitation measurements for October 1973 to September 1974 from a nearby gauging site were used and the Continental Maritimes region was applied. The resultant simulated yield increase for the logged basin in 1974 was 46.3 mm, therefore, the estimated total yield for 1974 on the logged basin was 123.8 mm. The measured yield from the logged basin in 1974 was 137.3 mm. The simulated yield is about 10% lower than the actual yield. This is a reasonable estimate of simulated yield because the model does not take into account basin storage conditions.

E. Data Preparation and Use

1. Data Preparation Steps

Base flow information may be the most difficult information to obtain. Water Survey of Canada have flow records for many larger basins (i.e., permanent streams) and their records could be checked for availability of flow data. If data are not available for the experimental basin, perhaps data from a nearby basin of similar characteristics could be used. Additionally, the Provincial Dept. of Environmental Protection may have detailed flow data for foothills streams - particularly for streams of first, second and third order. Finally, actual measurements could be taken. FMF has completed a hydrologic operational manual used to estimate streamflow in the region (Hydroconsult *in press*). The approach uses equations to predict streamflows. During base flow conditions very few measurements would be required to obtain useful information.

Detailed precipitation information is available from Environment Canada. Data from a range of sites can be obtained. One should choose gauging sites that surround the study basin and which correspond to major elevation changes. A GIS may be a useful tool for analyzing the influence of each gauging site on the study basin.

Forest Inventory data are available in a range of formats depending upon the region of the province being studied. With all inventory data, the objective should be to aggregate the data so that the number of records are as few as possible while detail is maintained in the following key areas:

1) cutblock date of harvest
2) cutblock elevation
3) cutblock aspect
4) stand species surrounding the cutblock
5) regeneration species proposed for the cutblock

For each of these criteria one must calculate the area and the number of cutblocks in each aggregate. These summations are then used to calculate the average cutblock size for each aggregation. Additionally, growth parameters must be assigned to the species fields (surrounding stand species and regeneration species).

Use of spatial inventory data that can be processed with a GIS is recommended. This may reduce the time involved in preparing the data and allow more time for analysis. Using the inventories (see section II - Data Requirements) the initial step in data preparation requires an overlay to: 1) - determine standing timber adjacent to cutblocks and 2) - determine the dominant tree species harvested in order to assign regeneration parameters. (Regeneration parameters might be available from silvicultural records, but if not pre-harvest inventory can be used.)

Determining the adjacent standing timber can be approached in two ways. 1) The recommended approach is to look at a buffer area surrounding the cutblock. This is most easily accomplished with a GIS. From the stands within this buffer area select a representative stand type and assign its stand height, dominant tree species and basal area to the surrounding stand information. When considering the representative stand there are a few items to consider. The prevailing wind direction has a major influence on the aerial distribution of snow, so perhaps the stand on the side of the prevailing wind should be selected. However, one must also consider the total area represented by that stand. The buffer size should be sufficient to obtain a representative tree height for the surrounding stand as tree height and wind influence snow in the cutblock. 2) An alternative approach that was employed in this study is to use the inventory types from the harvested block as representative of the surrounding timber. With this approach it is also necessary to chose a representative stand.

Each cutblock should have one aspect assigned to it. With a GIS and spatial inventory, this step is more complicated than using a visual approach, but the resulting information is more accurate. Some common approaches might be to use the midpoint of the cutblock or take the average of several sample points. Cutblock aspects for this study were assigned manually using topographic contours.

Cutblock elevation should also be assigned while determining aspect. Once again the GIS is the best tool for this procedure. In this study, cutblock elevation was assigned based on average elevation of the basin. The model requires that a number be entered into the elevation field or a program error will result.

Tree species assigned to the surrounding stand and regenerating stand must be one of those defined in the model which are typical to either the Rocky Mountains or Continental Maritimes regions. Once species are assigned, growth parameters for those species can be added. The model provides a separate table where coefficients for user defined regeneration growth functions can be added. The user must provide a name for the growth functions and then attach the name to the inventory record where the function is to be applied. The growth functions include a tree height function and a basal area function. Swanson, R.H. & Associates (1996) have added functions to the model from the Phase 3 Fully Stocked Yield Tables. These functions were used in the study. Growth potential is the last data input requirement. Maximum growth potential parameters are required for each species. These parameters include maximum basal area and maximum tree height, as well as the years required to reach these values. Rotation age (for the species involved) may be the most suitable time span to use for tree height. The following growth values were used in this study:

1) Pine and Spruce types
    - 40 m^2 maximum basal area in 80 years
    - 25 m tree heights in 120 years

2) Deciduous types
    - 30 m^2 maximum basal area in 30 years

- 20 m tree heights in 30 years.

The final step in data preparation is to aggregate the stand level information on species, height, aspect, surrounding stand type and regeneration type as well as sum the respective areas and count the number of blocks in each aggregate . This step deletes the block level information. The average block size can then be determined using the summed areas and the block count. With the fields set up in the same format as required by the WRNSFMF model, the data can be exported to an Access database. From there it can be cut & pasted into the Operational Units file which stores the operational data for running simulations. The Operational Units file <u>must</u> be used for the data. Another file cannot be selected in place of the Operational Units file. Additionally it is critical that the scenario name, used to identify the data from a simulation run, be copied to the Operational Units Control file so that the scenario name will appear in the user control screen. Once the data are loaded into the Operational Units file it can be viewed and edited from the model's user control screen. As well, other data such as climate, water yield, growth functions and calibration values can be edited from inside the model.

Using the model requires some knowledge about the windows environment and databases (in particular Microsoft Access). WRNSFMF User's Manual (Swanson, R.H. & Associates 1996) provides a thorough description of how to install and use the model. It also provides background material on hydrologic processes and their influence on water yield.

2. Standardizing Data Manipulation

Many of the steps taken to prepare data for this study could be standardized through a GIS, and programming procedures or macros. FMF is currently working with The Forestry Corp and the consultant for this study to standardize some procedures in preparing datasets for WRNSFMF. Some of the programmed procedures might include: 1) overlay and selection of surrounding stand and regeneration information, 2) assignment of aspect and elevation, 3) lookup routines to assign growth functions and maximum growth parameters and 4) a dataset ready to be incorporated into the WRNSFMF model.

3. Potential Modifications

Occasionally the model will hang on system errors that are encountered. Error messages are provided, however once the system hangs it is difficult to correct the error without exiting the program. The most common error encountered during this study was from empty fields. It is critical that all fields contain data prior to running a simulation. If an error should be encountered it is best to exit from the model, re-enter the model and correct the error before running another scenario. Modifications could include a check for empty fields and a warning to the user before the simulation run begins.

The percent harvested field is not updated as new information is keyed until after a scenario has run or the program is exited and re-started. The first time user should be aware of this as it might be confusing looking at the percent field knowing the area cut is larger than the screen field shows. Incorporating a procedure to update the field immediately after a keyed change would be beneficial. This error may already be corrected in an updated version.

Harvest data must always be entered into the Operational Units file as noted above. It would be convenient for the user to be able to pick a file to use as the operational units file rather than copying data into the file.

New scenario names must be added manually to the Control Units file. An event button could re-compile the control units file based on the information in the operational units file. This would eliminate the need to copy the scenario names to another file and would ensure the scenario names are spelled exactly the same between files. The model programmer is presently working on modifications to improve functioning of the operational units file and the control units file.

Quitting the WRNSFMF program automatically quits Access. Sometimes this is inconvenient when closing WRNSFMF only for the purpose of modifying files. An event button could be setup for closing the model while leaving Access and the WRNSFMF database open. The model programmer has constructed the 'Quit' button in this manner so that user's do not have direct and unlimited access to the database. This is a reasonable concern given that data could be modified inadvertently.

VII. Conclusions

Forest harvesting and silvicultural practices are the most well understood techniques for manipulating water yields. Operational harvesting strategies can be implemented to alter the effects of runoff. Using the WRNSFMF model, this study showed that several factors can significantly impact changes in water yield. The highly sensitive factors include area cut, block size and aspect. Increasing area cut can significantly increase the change in yield. The cutting pattern also affects yields. Small cutblocks will maximize snow accumulation and generate higher yields than large cutblocks. In high wind areas small cutblocks are also advantageous at minimizing changes in yield. Forest harvesting from south aspects will generate greater yield changes than from north aspects. Silvicultural practices influence water yields. Site conditions promoting good re-growth tend to reduce the impact on yields. Regeneration species which rapidly increase in height and basal area will significantly reduce yield changes. And finally, high elevation basins tend to generate greater yield changes than low basins (using a snow and rain hydrologic region). With these sensitivity issues in mind and the simulation model at hand, the forest management planner has the tools to make water yield change predictions with a level of confidence and understanding.

Modeling water yield changes is simplified with WRNSFMF. With some knowledge of database manipulation users can put together scenarios to estimate water yield generation. Structuring the inventory data requires a systematic approach to ensure the necessary information is included and aggregated appropriately before being imported to the Access database. Local climate and base flow information will make yield simulations more accurate. Testing various parameters such as precipitation, harvesting and silvicultural conditions is an easy process once the inventory files have been constructed and the climate and base flow data have been acquired. The model contains sufficient sample data that a user can run test simulations to study its procedures and output.

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Appendix I

Seven values for precipitation were tested against historical harvest information. Mean monthly values from Edson, for the period 1970-1990, were used as average conditions. Average wind speed at Edson is recorded as 7.9 km/hr predominantly out of the west. Further adjustments to precipitation values were made based on the average condition. Precipitation values are shown in Table A-1. Comparative results of testing these precipitation values against the Rocky Mountains and Continental Maritimes regions are shown in Tables A-2.1 and A-2.2.

Table A-1 Precipitation values

Class No.	Description	(mm)
1	average monthly values	557.9
2	summer (April-Sept.) values doubled	994.3
3	winter (Oct.-Mar) values doubled	679.4
4	summer values doubled and the winter values divided in half	922.9
5	winter values doubled and the summer values divided in half	994.3
6	summer and winter values doubled	115.8
7	summer and winter values divided in half	230.0

Table A-2.1 A Comparison of Rocky Mountains and Continental Maritimes Regions with Modified Precipitation Regimes

Drainage Name	Basin Size	Harvested Area		Region	Base Yield	Maximum yield increase over base yield for three precipitation classes					
		(ha)	(%)			No. 1 (Ave)		No. 2 (Sum x2)		No. 3 (Win x2)	
	(ha)				(mm)	(mm)	(%)	(mm)	(%)	(mm)	(%)
Oldman-2	1700	574	34%	RM	77.6	17.4	22.4%	18.6	24.0%	19.6	25.3%
				CM	77.6	12.1	15.6%	16.3	21.0%	10.0	12.9%
Oldman-3	1490	475	32%	RM	155.3	10.1	6.5%	11.8	7.6%	10.2	6.6%
				CM	155.3	9.3	6.0%	11.5	7.4%	6.8	4.4%
Oldman-1	1640	1539	94%	RM	137.3	25.7	18.7%	27.8	20.2%	27.1	19.7%
				CM	137.3	17.8	13.0%	20.3	14.8%	15.9	11.6%
Fish	2560	1792	70%	RM	101.1	13.3	13.2%	13.4	13.3%	14.0	13.8%
				CM	101.1	13.4	13.3%	15.1	14.9%	12.1	12.0%
Oldman-4	1970	796	40%	RM	202.7	9.3	4.6%	10.4	5.1%	8.1	4.0%
				CM	202.7	8.0	3.9%	9.7	4.8%	6.8	3.4%
Pine-2	2390	289	12%	RM	198.5	2.8	1.4%	3.1	1.6%	3.1	1.6%
				CM	198.5	3.0	1.5%				
Pine-1	2210	1290	58%	RM	296.9	12.4	4.2%	13.7	4.6%	12.9	4.3%
				CM	296.9	13.3	4.5%				
Edson R. -5	700	383	55%	RM	271.4	10.3	3.8%	12.8	4.7%	12.0	4.4%
				CM	271.4	16.9	6.2%	16.9	6.2%	16.8	6.2%
Edson R. -4	2310	1152	50%	RM	266.0	9.7	3.6%	11.6	4.4%	11.6	4.4%
				CM	266.0	12.5	4.7%				
Hendrickson	2200	94	4%	RM	129.2	1.9	1.5%	1.8	1.4%	2.4	1.9%
				CM	129.2	2.9	2.2%				
Fox-2	1820	1133	62%	RM	102.2	13.7	13.4%	14.5	14.2%	14.3	14.0%
				CM	102.2	16.6	16.2%				
Fox-1	1230	834	68%	RM	132.9	21.8	16.4%	22.5	16.9%	19.9	15.0%
				CM	132.9	16.3	12.3%				
Anderson-2	1970	759	39%	RM	107.9	14.0	13.0%	15.6	14.5%	13.9	12.9%
				CM	107.9	8.6	8.0%				
Unnamed-2	880	248	28%	RM	86.8	6.6	7.6%	8.1	9.3%	7.5	8.6%
				CM	86.8	6.1	7.0%	6.3	7.3%	5.9	6.8%
Anderson-1	1070	600	56%	RM	205.9	21.5	10.4%	21.1	10.2%	22.4	10.9%
				CM	205.9	23.6	11.5%	24.6	11.9%	22.5	10.9%
Quigley	1680	803	48%	RM	192.0	12.5	6.5%	13.7	7.1%	14.8	7.7%
				CM	192.0	15.7	8.2%				

Table A-2.2 A Comparison of Rocky Mountains and Continental Maritimes Regions with Modified Precipitation Regimes

Drainage Name	Basin Size	Harvested Area (ha)	(%)	Region	Base Yield	Maximum yield increase over base yield for four precipitation classes: No. 4 (Sum x2, Win /2)		No. 5 (Win x2, Sum /2)		Nos. 6 and 7 (Ave. x2 [1], Ave./2 [2])	
						(mm)	(%)	(mm)	(%)	(mm)	(%)
Oldman-2	1700	574	34%	RM	77.6	25.0	32.2%	20.8	26.8%	17.4 [1]	22.4%
				CM	77.6	23.1	29.8%	5.8	7.5%	12.1 [1]	15.6%
Oldman-3	1490	475	32%	RM	155.3	15.3	9.9%	11.5	7.4%	10.1 [1]	6.5%
				CM	155.3	15.1	9.7%	4.2	2.7%	9.3 [1]	6.0%
Oldman-1	1640	1539	94%	RM	137.3					25.7 [1]	18.7%
				CM	137.3					17.8 [1]	13.0%
Fish	2560	1792	70%	RM	101.1						
				CM	101.1						
Oldman-4	1970	796	40%	RM	202.7					9.3 [2]	4.6%
				CM	202.7						
Pine-2	2390	289	12%	RM	198.5						
				CM	198.5						
Pine-1	2210	1290	58%	RM	296.9	14.4	4.9%	14.2	4.8%		
				CM	296.9						
Edson R. -5	700	383	55%	RM	271.4						
				CM	271.4						
Edson R. -4	2310	1152	50%	RM	266.0						
				CM	266.0						
Hendrickson	2200	94	4%	RM	129.2						
				CM	129.2						
Fox-2	1820	1133	62%	RM	102.2						
				CM	102.2						
Fox-1	1230	834	68%	RM	132.9						

				CM	132.9	
Anderson-2	1970	759	39%	RM	107.9	
				CM	107.9	
Unnamed-2	880	248	28%	RM	86.8	
				CM	86.8	
Anderson-1	1070	600	56%	RM	205.9	
				CM	205.9	
Quigley	1680	803	48%	RM	192.0	
				CM	192.0	