Applying Hydrologic Principles to the Management of Subalpine Forests for Water Supply

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Abstract--WRENSS HP is used to estimate an increase in yield at Fool Creek, Colorado, of 62 mm compared to an actual increase of 67 mm. Similarly, at Cabin Creek, Alberta, WRENSS-HP estimated 7 mm compared to an actual increase of 17 mm. If representative and accurate precipitation data were used, long term actual annual water yields were estimated with no error at either Fool Creek or Cabin Creek. The predicted effectiveness over a 100 year implementation period of 10 ha clear cut blocks as a practice in increasing water yield was virtually identical to that of 1 ha clearcuts if winter wind speeds averaged less that 1 m s^{-1}. At a wind speed of 5 m s^{-1}, the 1 ha clear cut practice produced an increase three times as great as the 10 ha blocks, mainly because of the protection these smaller clearcuts afford accumulated snow from wind and subsequent evaporation.

The management of forests is becoming increasingly complex as various user groups place often conflicting demands upon the same land base. Water users are one such group. Their demands for more water are apparently insatiable.

One of the roles of forest land is watershed. This is a geographical fact that cannot be dismissed. The subalpine forests of the west are among the most important of these watershed as the streams originating on them flow through very arid but valuable agricultural land enroute to the sea.

The virgin forest is not the most efficient watershed in terms of water supply. Many forests can be physically configured, using various clear cut patterns, to make them yield from 20% to 40% more water each year than the uncut condition. Scientists working in the field of forest hydrology have sought to understand the hydrologic system that forests represent and to apply that understanding to the development of management techniques that can be used to provide predictable increases in water yield. My purpose in this paper is to illustrate how the hydrologic procedure presented in the WRENSS handbook (U.S. Forest Service 1980, Troendle and Leaf 1980) can be used to estimate changes in water yield, and the accuracy of the results obtainable with it.

The Hydrologic Procedure in WRENSS

WRENSS-HP

The WRENSS handbook (U.S. Forest Service 1980) contains a hydrological procedure (Troendle and Leaf 1980) that represents the state of the art for estimating the change in evapotranspiration that will occur when either clear cutting or reforestation occurs on watersheds in the United States and much of Canada (I will call the hydrology portion WRENSS-HP to avoid confusion with the other WRENSS routines.). A change in annual evapotranspiration is a necessary and sufficient condition to affect an eventual (and comparable) change in annual water yield.

Evapotranspiration quantity (ET) is the only portion of a watershed's water balance that we can manage with appropriate forestry practices. WRENSS-HP estimates of evapotranspiration can be used in two ways: (1) directly as estimates of changes in water yield that can be affected by forest cutting; or (2) indirectly within the water balance equation to estimate generated runoff (GRO). The difference in annual evapotranspiration that WRENSS-HP estimates for a forested watershed under uncut and cut conditions is a valid approximation of the change in annual water yield that one can expect from that watershed.

Any land management strategy designed to increase water supply through some form of timber harvest must therefore

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reduce evapotranspiration (the amount of water lost to the atmosphere as evaporation from wet surfaces such as the snowpack, leaves, litter and other debris, and from the soil via the stomata on the leaves of trees and other vegetation) if it is to be successful. Contrary to what is often popularly believed, the maximum reduction in evapotranspiration is not generally achieved by removing all of the trees from a watershed. The evaporation process is too complex for such a simple solution. Evapotranspiration is affected by; (1) energy form (e.g. air temperature, solar radiation, wind, etc.), (2) water vapor concentration (e.g. humidity of the air and motion of the air next to any surface with water on it) and (3) water availability (e.g. surfaces, such as leaves or litter, upon which water can accumulate or the proximity of roots to water in the soil). The rearrangement of a forest from one uniformly vegetated to one with discontinuities at tree clearing edges alters all of these. In general, one must reduce the number of trees drawing upon the soil moisture, reduce the total amount of tree canopy, and protect cleared surfaces (and new growth on them) from direct exposure to the sun and wind. The physical configuration of a forest that is to be optimized for supplying water must be carefully crafted and maintained to minimize evapotranspiration.

The WRENSS-HP procedure for estimating evapotranspiration is based on two comprehensive hydrologic models; but WATBAL (Leaf and Brink 1975), is the one most applicable to the snow dominated subalpine forest. The WATBAL model calculates daily ET based on a set of model parameters specific to a particular watershed and daily inputs of precipitation, temperature, etc. The parameters of WATBAL can be adjusted to allow for precipitation (P) and climatic data that may be only indices of true precipitation and climate. The daily values of generated runoff, (GRO) equation [1], that are calculated by WATBAL, can be routed through the storage components of a specific watershed, upon which it has been calibrated, to produce an accurate estimate of each day's streamflow.

$$GRO = P - ET \qquad [1]$$

In contrast, the WRENSS-HP procedure estimates seasonal evapotranspiration as a function of seasonal precipitation within a broad climatic region. It contains no parameters to adjust for indexed precipitation. Nor does it contain watershed descriptors that would allow one to calculate changes in storage (ΔS). Since it contains no provision for estimating storage, nor changes in storage, it cannot be used to estimate the amount of water (routed streamflow) that will be present in a stream channel at any given time. The role of storage is somewhat clearer in the alternate form of the definition for generated runoff, equation [2], where water yield (Y) is streamflow divided by watershed area.

$$GRO = Y \pm \Delta S \qquad [2]$$

With WRENSS-HP, an estimated change in generated runoff for a year or possibly even several years, will generally not be directly verifiable as a change in measured water yield, as the measured yield may be influenced by the unknown magnitude of change in watershed storage. Clearly, generated runoff (eq. [2]) is equal to water yield only when S is zero. In fact, the only circumstances under which GRO, as calculated from WRENSS HP evapotranspiration estimates and equation [1], will equal annual yield or streamflow are: (1) The precipitation data must be accurate for and representative of the watershed under consideration; (2) Changes in storage must equal zero or be averaged over a sufficiently long time period so that their algebraic sum is zero. Although the authors of WRENSS HP suggest that it can be used to estimate both seasonal and annual evapotranspiration, only the annual estimates are verifiable within the water balance equation [1] (within the limits imposed by changes in annual storage). Because of short term storage in the snowpack and soil, the WRENSS HP estimates of seasonal evapotranspiration can only be verified by on-site measurements of seasonal evapotranspiration. Thus one should generally consider the seasonal ET estimates only as intermediate steps in the estimation of annual evapotranspiration.

Availability of WRENSS HP

The complete WRENSS handbook is available from the U. S. Environmental Protection Agency (U.S Forest Service 1980). The nomograms in the hydrology chapter (Troendle and Leaf 1980) can be used to calculate annual evapotranspiration under various forest cutting options. I digitized the nomograms for the snow dominated regions, fitted them to second order equations, and prepared an interactive program for the Hewlett Packard 9825A calculator. These equations have since been used to produce interactive programs for an IBM PC/XT or compatible microcomputers (Bernier 1986). The microcomputer version is the easiest to use, but it may give results slightly different from the nomograms as the snow accumulation and snow evaporation routines are not exactly the same as those published in the EPA handbook.

How to Use WRENSS HP

In order to estimate changes in water yield that can be expected to occur under a forest management scheme, WRENSS-HP is used to calculate the annual evapotranspiration for some baseline condition (usually fully treed), and under the same overall precipitation regime but with some de or re forestation. The difference between the two values is the estimated change in annual yield. In partially clear cut situations, WRENSS-HP apportions differing amounts of precipitation to the cut and treed areas on the following bases:

1. In clearcuts, with maximum windward dimensions less than approximately 15 tree heights, snow accumulates preferentially, presumably at the expense of the surrounding treed area;

2. In clearcuts with windward dimensions greater than 15 tree heights, snow may be removed from a clearing by wind and either sublimate while in transport or be redeposited in the downwind treed areas; this transport can be switched off in our microcomputer versions (Bernier 1986);
3. If the surface of a clear cut is aerodynamically rough, then snow may be retained in place regardless of the windward dimensions.

Some evaporation may occur in situ from the surface of the snow accumulated within a clear cut. In our microcomputer versions of WRENSS-HP (Bernier 1986) evaporation from snow occurs as a function of the wind speed in the clear cut. Our studies have shown that the wind speed 2 m above the surface of clearcuts greater than 20 tree heights across is the same as would occur at either 10 m above the canopy or in completely open situations. In clearcuts smaller than 20 tree heights across, wind speed and evaporation from the snow surface in the clear cut is reduced as a function of clear cut dimensions.

Data Requirements for WRENSS-HP

Land managers have considerable latitude in the use of WRENSS-HP to estimate treatment effects on annual yields. Site specific climatic and streamflow data are not always necessary. A current inventory of timber volume is desirable, but by no means necessary, as estimates by knowledgeable personnel are quite sufficient in most instances.

First Year or Initial Effects

Precipitation by WRENSS-HP season[2].--The distribution of precipitation between seasons is more important when WRENSS-HP is used solely to estimate changes in annual yield than is the absolute amount of precipitation. The amount and representativeness of the precipitation data are of paramount importance in one wishes to estimate actual annual water yield. We have used 5 to 10 year averages or the precipitation from the years with the highest and lowest annual streamflow and noted little effect on estimated change in annual water yield (Swanson and Bernier 1986). These data can be obtained from something as simple as an hydrologic atlas for the area that has isopleths of mean annual precipitation and mean annual water yield. Any reasonably local precipitation station's data can be used to apportion annual precipitation among the percentages applicable to the WRENSS-HP seasons.

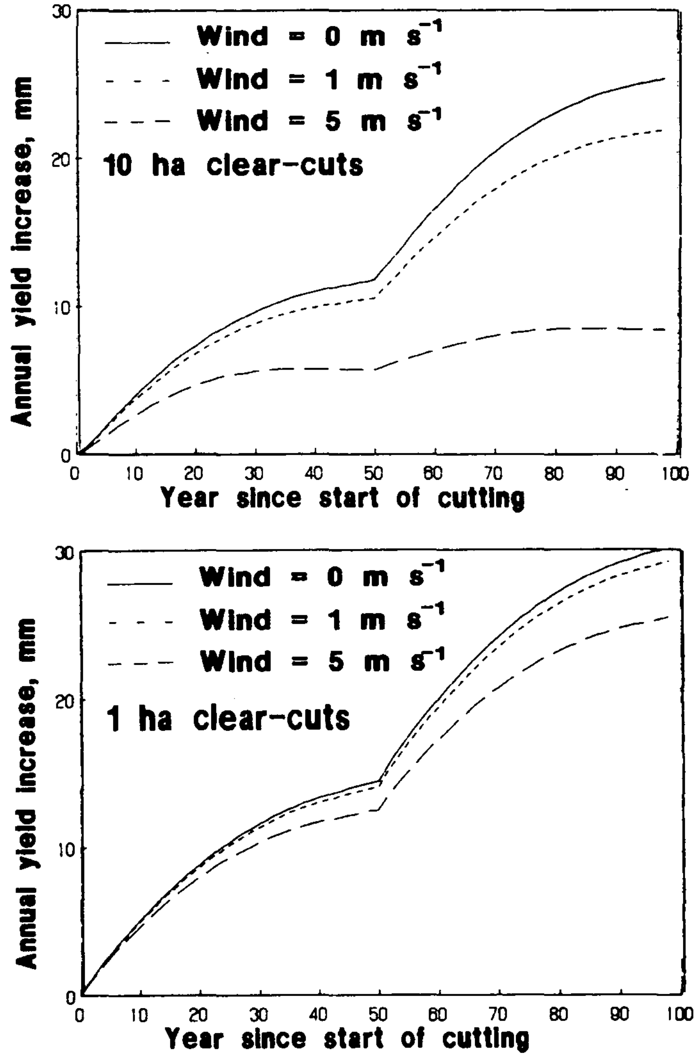

Figure 1.--Progressive effect on annual water yield of annual clear cutting of alternate blocks of mature subalpine spruce-fir forest at 50 year re entry intervals on a watershed throughout a 100-year rotation. With winter wind speeds (October to April) of 1 m s^{-1} or less, the 10-ha clear cut blocks (a) produce only a slightly lower increase in yield when fully implemented than the 1-ha blocks (b). However, the difference in the effectiveness for increasing water yield of the two clear cut sizes becomes much more noticeable when winter wind speeds are much greater than 1 m s^{-1}.

An estimate of average wind speed during the winter and spring.--The windiness of a site has a very marked effect on evaporation of snow (fig 1a). If wind speeds are generally less than 1 m s^{-1}, then wind speed can be ignored (fig 1). If no values for wind speed are available, then one can estimate effects for a range of values and try to verify the actual speed at some later time. If in doubt, it is best to use smaller clearcuts as the surrounding trees protect the snow surface from wind, and ensure higher water yields (fig 1b).

The tree species present, its height and the basal area for a full occupancy (mature?) stand.--This is not critical as estimates of evapotranspiration are made using fractions of this value rather than the absolute quantity.

[2] The months used in the WRENSS HP procedure's seasons do not correspond to the normal winter, spring, summer and fall periods, although they use the same names!

Basal area that might remain within a clear cut after clearcutting.--In Canada and probably in the United States, some tree species are not considered to have sufficient value to harvest, and are left standing. These generally occupy less than 15% of the total area of any given clear cut, but may need to be taken into account.

The type of treatment, or in the case of clear cutting, the size of clear cut, either in dimensions or as an area.--Our microcomputer version of WRENSS-HP queries one for the clear cut dimension parallel to the prevailing wind direction (Bernier 1986). If this information is not available, then the program calculates it as if it was a square clear cut block of the given area.

The area to be treated and the total area of the watershed.--If the estimates are not for a specific location, then use some convenient unit area.

The general topographic aspect of the area under investigation.--We use east west aspects if no site specific information is available. WRENSS-HP produces considerably different yield estimates for north and south aspects, so if these are known to apply, they should be used.

Effects Throughout a Rotation

Rate of height and basal area regrowth.--We have used a linear function from 0 to maximum height or basal area over the proposed rotation duration to produce the estimates in figure 1. If local data for growth are available, they can be input on a year by year basis to estimate the effect of regrowth on the change in water yield that will occur each year.

The amount of new cutting that will occur and at what frequency.--For example, areas to be harvested in Canada are delineated and divided into a number of areas to be cleared each year. If subsequent cuts in the same watershed are made at five year intervals, than new clearcuts should be introduced into the calculations at five year intervals throughout the rotation.

Mode of implementation.--If a forest is clear cut in an alternate block manner where the treed block between clearcuts are removed at some later time period, the time when these trees are to be removed relative to the state of regrowth in any adjacent clear cut blocks must also be considered.

For example, in Alberta, an area to be managed as one unit within a 100-year rotation is subdivided into 5 compartments. The second and subsequent compartments are not entered until all of the timber from prior numbered compartments has been removed. All of the trees in a compartment are removed during a 20 year period, half in the first 10 years, the uncut intervening blocks in the second 10 years. The second entry to remove the intervening treed blocks creates clearcuts that are surrounded by trees 1 to 2 m tall compared to the original forest at 20 m tall and thus less under the wind speed reduction influence of their surroundings than those clearcuts of the first entry.

Examples Using WRENSS HP

Perhaps the best way to demonstrate the WRENSS HP procedure is to show how it has been applied in various situations. I have chosen as examples the Fool Creek watershed near Fraser, Colo., and the Cabin Creek watershed near Banff, Alberta. Both watersheds are in the subalpine zone. The vegetation on both is primarily spruce fir and lodgepole pine. Both have been partially harvested and the effect of that harvest on streamflow is known. The harvest in small clearcuts at Fool Creek has produced an increase of 89 mm (1956 to 1972, Alexander and Watkins 1977); the commercial sized clearcuts at Cabin Creek 17 mm (1975 to 1984, Swanson et al. 1986).

Precipitation data from two sources are available for both watersheds; the Fool Creek tower and Fraser Experimental Forest headquarters for Fool Creek, the CON 5 station and that from two higher elevation stations weighted in accordance with the Thiessen polygon method, on Cabin Creek. Most of Fool Creek's precipitation occurs between October and May (table 1), most of Cabin Creek's precipitation occurs between February and June (table 2). Their subsurface storage volume is quite different as Fool Creek is on granitic material with a shallow porous mantle (approximately 1 m thick); Cabin Creek on sedimentary material with a porous mantle 6 to 8 m thick.

Change in Estimated Yield as Affected by Source of Precipitation Data

One of the common desires of those using WRENSS-HP is to check its output against measured values. The closeness of any comparison of actual and estimated change in annual water yield or in total annual water yield is influenced by both the representativeness of the precipitation data used and any water stored on a watershed which may appear as streamflow in the next or subsequent years. Differences between WRENSS-HP estimated and measured changes in yield are not particularly affected by the precipitation data used, as long as it is from the same vicinity. For example if the Fraser Experimental Forest headquarters site precipitation data is used to estimate the change in water yield on Fool Creek, the mean value predicted, 58 mm compares favorably the 62 mm (table 3) obtained with the Fool Creek wind tower data. However, the total annual flow predicted with the headquarters data is only 203 mm compared to the 318 mm predicted with the wind tower data (table 3). The differences are more evident on Cabin Creek. When CON 5 precipitation is used in WRENSS HP, the total yield and change in annual yields predicted (table 3) are 195 and 11 mm versus 317 and 7 mm if the Thiessen polygon weighted precipitation data are used (actual annual flow 1975 1984 and calculated increase were 316 and 17 mm, Swanson et al 1986). Although the predicted yield increase is only 40% of actual on Cabin Creek, they are both of the same order of magnitude and neither the predicted

Table 1.—Seasonal[1] precipitation (mm) (Haeffner 1971) and measured annual water yield at Fool Creek, Fraser Experimental Forest, Colorado.

	FEF headquarters			Fool Creek wind tower			Annual	
Year	Winter	Spring	Summer	Winter	Spring	Summer	Yield	Change[2]
1967	200	186	114	263	236	97	280	79
1968	181	131	111	249	176	127	232	48
1969	185	243	136	237	268	132	308	64
1970	264	172	130	350	204	168	376	53
1971	262	169	98	360	226	123	401	91
Mean	218	180	118	292	222	130	319	67

[1] Seasons are: Winter, 1 Oct-28 Feb; Spring, 1 Mar 30-Jun; Summer, 1 Jul-30 Sep.

[2] Change in water yield as estimated by paired basin analysis (Alexander and Watkins 1977).

Table 2.—Seasonal[1] precipitation (mm) and measured annual water yield at Cabin Creek subbasin, Marmot Experimental Watershed, Alberta.

	CON 5 Station			Thiessen Polygon weighted[2]			Annual	
Year	Winter	Spring	Summer	Winter	Spring	Summer	Yield	Change[3]
1977	119	253	221	123	276	259	212	-13
1978	137	235	168	185	336	226	335	-2
1980	218	302	221	146	348	272	377	53
1981	189	362	123	236	421	146	503	103
1983	130	243	165	137	294	185	247	7
77-83[4]	159	279	180	165	335	218	335	30
75-83[4]	175	247	184	-	-	-	316	17

[1] Seasons are: Winter, 1 Oct 28-Feb; Spring, 1 Mar-30 Jun; Summer, 1 Jul-30 Sep.

[2] Data from Davies and Kallenbach (1985).

[3] Change in yield as estimated by paired basin regression (Swanson et al. 1986).

[4] Precipitation data for 1979 and 1982 not included because streamflow is not available for these years.

Table 3.—Estimated and measured values (mm) of long term annual water yield and change in annual water yield with harvest at Fool Creek, Colorado, and Cabin Creek, Alberta. Period of record: Fool Creek/FEF Headquarters, 1965-1971; Cabin Creek, 1975-1983 (1979 and 1982 omitted).

	Seasonal precipitation			Yield		Change in Yield	
Source of data	Winter	Spring	Summer-Fall	Predicted	Actual	Predicted	Actual
FEF HEADQUARTERS	218	180	118	203	319	58	67
FOOL CREEK TOWER	292	222	130	318	319	62	67
CABIN CREEK, CON-5	168	252	187	195	316	11	17
Thiessen POLYGONS	207	314	226	317	316	7	17

nor the actual water yield increases are physically significant to water supply.

The proper choice of precipitation data often is a problem in using WRENSS-HP or any water balance procedure. We rarely have the wealth of data available for both Fool Creek and Cabin Creek. As indicated above, precipitation data from nearby stations is probably suitable for use in WRENSS-HP to estimate changes in annual yield. However, the precipitation data ordinarily available will rarely be representative of the watershed in question, even if it is collected on it. Precipitation stations are often located near a stream gauge which is always at the lowest elevation on a watershed. Since precipitation generally increases with elevation, the precipitation measured at the topographic low will normally be less than that occurring at higher elevations on the watershed. Thus WRENSS-HP estimates of actual annual yields obtained from the water balance equation [1] will generally be less, (often much less as with CON 5 data from Cabin Creek) than measured.

Change in Estimated Yield as Effect by Storage

One should not expect either the change in yield or the total yield for any single year to match that actually measured. Year to year variation in estimated and actual changes in water yield should be expected, especially in watersheds with considerable storage, e.g. Cabin Creek, table 4, all years shown. However, even at Fool Creek, which has almost no storage, the predicted and measured changes in water yield for a given year differ rather widely, e.g. table 4: 53 mm versus 79 mm in 1967; 58 mm versus 48 mm in 1968.

Since changes in storage have such a strong effect on comparisons of measured versus actual data, what period of time should one use to perform such comparisons? I suspect that 5 to 10 years of data should be sufficient.

Discussion

Once one has established a proper forest configuration to minimize evapotranspiration, then the increased volume of water that can be extracted from a watershed is directly proportional to the area of the watershed so treated. Our ability to predict water yields that would occur in the absence of treatment is insufficient to detect increases after treatment that are smaller than about 20%. However, this is a measurement problem, and should not be used as an excuse to not manage for increased yield.

The slow growth of subalpine forests makes water yield increases fairly permanent. The same slow growth may make it almost impossible to restructure a forest for water yield improvement after it has be cleared in some less than optimum manner. For instance, if the best water yielding practice is found to be a 50-50 patchwork of 1-ha clearcuts, than a prior harvest in clearings larger than this will preclude an optimum restructuring for most of the rotation period. However, portions of the forest that have not been harvested can be configured in the optimum arrangement.

Small clearings and windthrow are always a subject of considerable discussion among foresters. Full wind speeds develop 10 to 15 multiples of the height of an object downwind

Table 4.--Effect of year to year carryover storage on estimated and measured values of annual water yield and change in annual water yield with harvest at Fool Creek, Colorado, and Cabin Creek, Alberta.

	WRENSS-HP estimates			Measured			
Year	Wind (m/s)	Uncut (mm)	Cut (mm)	Change[1] (mm)	Yield (mm)	Change[2] (mm)	A/P[3]
Fool Creek - Precipitation data from Fool Creek Tower							
1967	3.5	235	288	53	280	79	0.97
1968	3.4	176	234	58	232	48	.99
1969	3.7	246	303	57	308	64	1.02
1970	4.4	321	389	68	376	53	.97
1971	5.1	324	390	66	401	91	1.03
Cabin Creek Precipitation data weighted by Thiessen Polygons							
1977	4.0	228	239	11	212	-13	0.89
1978	4.0	309	316	7	335	-2	1.06
1980	4.0	329	337	9	377	53	1.12
1981	4.0	382	383	1	503	103	1.31
1983	4.0	192	201	9	247	7	1.23

[1] Change is WRENSS HP estimated cut uncut water yield.

[2] Change is as estimated with paired basin regression (Fool Creek: Alexander and Watkins 1977; Cabin Creek: Swanson et al 1986).

[3] Actual measured streamflow after clear cutting divided by WRENSS HP estimated flow after clear cutting.

from it. The leeward edge of clearings greater than 10 to 15 tree heights across should therefore be the most vulnerable. On Fool Creek, where clearings ranged from 1 to 6 tree heights across, little blowdown occurred (Alexander 1967). I think that the Fool Creek results are indicative of what one should expect elsewhere provided the uncut stand is wind firm. With small clearings such as at Fool Creek, one must be careful in locating cutting boundaries if he wishes to take advantage of terrain situations that limit windthrow.

Watershed management cannot be effectively planned and implemented without the involvement of individuals trained in forest hydrology. There will always be a great deal of judgment in any management prescription. Research has provided good tools, but they are not "cook book" techniques. The application of methods to optimize timber harvesting patterns in specific watersheds must always be conditioned by local climatic and topographic conditions.

Literature Cited

Alexander, Robert R. 1967. Windfall after clearcutting on Fool Creek - Fraser Experimental Forest, Colorado. U.S. Dept. Agric., For. Serv., Rocky Mt. For. Range Exp. Stn. Fort Collins, CO., Research Note RM-92. 11 p.

Alexander, Robert R. and Ross K. Watkins. 1977. The Fraser Experimental Forest, Colorado. U.S. Dept. Agric., For. Serv., Rocky Mt. For. Range Exp. Stn. Fort Collins, CO., Gen. Tech. Rep. RM-40. 32 p.

Bernier, P. Y. 1986. A programmed procedure for evaluating the effect of forest management on water yield. Can. For. Serv., Nor. For. Centre, Edmonton, Alberta. Forest Management Note No. 37. 12 p.

Davies, Franklin D. and Bernd Kallenbach. 1985. Marmot Creek research basin precipitation analysis. Alberta Dep. Environ. Water Resour. Management Services, Technical Services Division, Edmonton, Alberta. 19 p. plus appendices.

Haeffner, Arden D. 1971. Daily temperatures and precipitation for subalpine forest, central Colorado. U.S. Dept. Agric., For. Serv., Rocky Mt. For. Range Exp. Stn. Fort Collins, CO. Res. Pap. RM-80, 48 p.

Leaf, C. F. and G. E. Brink. 1975. Land use simulation model of the subalpine coniferous forest zone. U.S. Dept. Agric., For. Serv., Rocky Mt. For. Range Exp. Stn. Fort Collins, CO. Res. Pap. RM-135, 42 p.

Swanson, R. H. 1980. Surface wind structure in forest clearings during a chinook. In Proceedings, 48th Annual Western Snow Conference, April 15-17, 1980, Laramie, Wyoming. p. 26-30.

Swanson, R. H. and P. Y. Bernier. 1986. The potential for increasing water supply in the Saskatchewan River system through watershed management. *In:* Canadian Hydrology Symposium CHS:86, June 3-6, 1986, Regina, Saskatchewan, p. 485-496. National Research Council of Canada, Associate Committee on Hydrology, Ottawa.

Swanson, R. H., D. L. Golding, R. L. Rothwell and P. Y. Bernier. 1986. Hydrologic effects of clear cutting at Marmot Creek and Streeter watersheds, Alberta. Can. For. Serv., Nor. For. Centre, Edmonton, Alberta. Information Rep. NOR-X-278. 27 p.

Troendle, Charles A. and Charles F. Leaf. 1980. Hydrology. Chapter III, p. III-1 to III-173. *In:* An approach to water resources evaluation of non-point silvicultural sources (a procedural handbook). U.S. Environ. Prot. Agency, Environ. Res. Laboratory, Athens, GA. EPA-600/8-80-012. 861 p.

U. S. Forest Service. 1980. An approach to water resources evaluation of non point silvicultural sources (a procedural handbook). U.S. Environ. Prot. Agency, Environ. Res. Laboratory, Athens, GA. EPA-600/8-80-012. 861 p.

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