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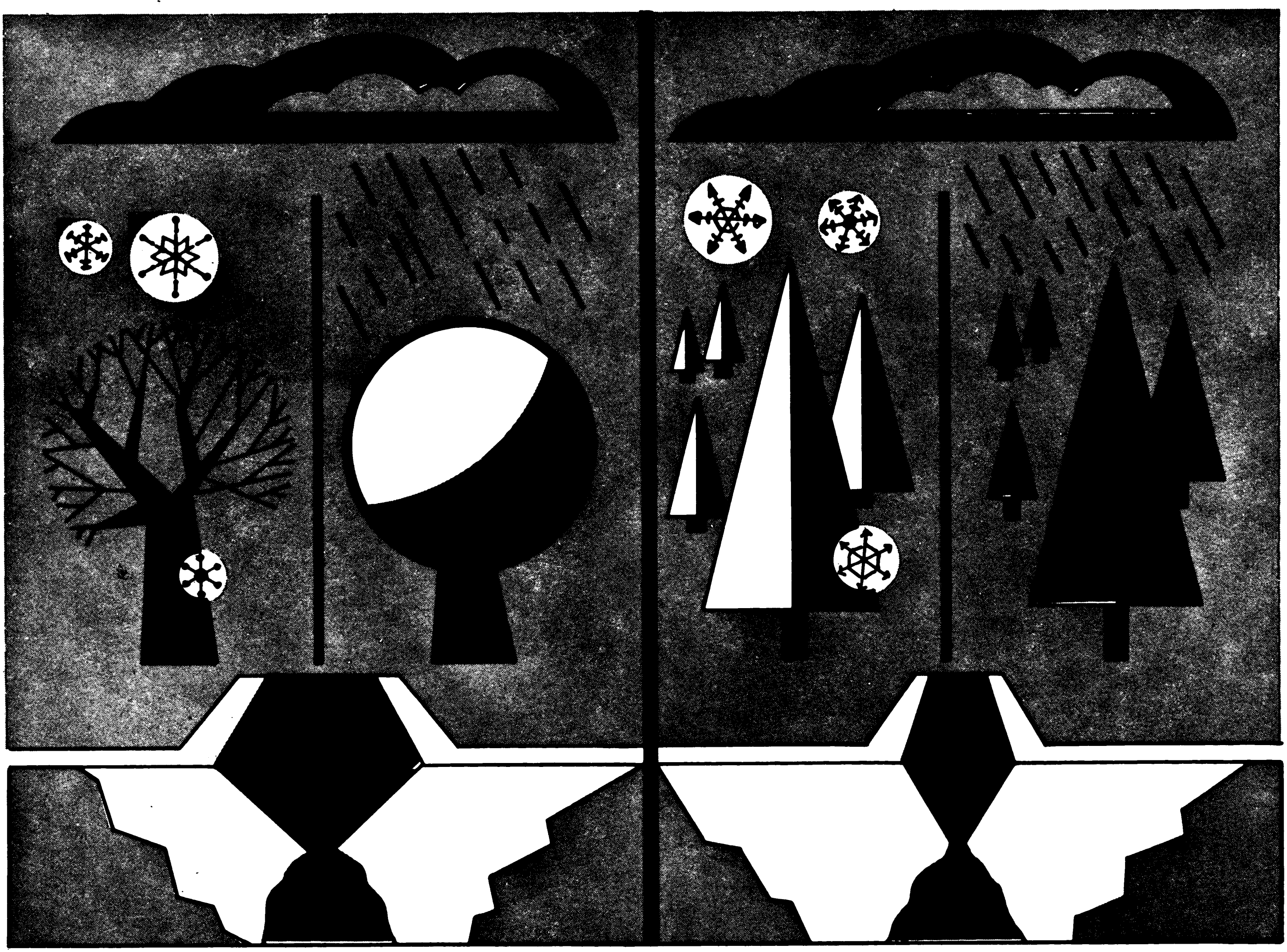
ESTIMATING WATER YIELD DIFFERENCES BETWEEN HARDWOOD & PINE FORESTS

AN APPLICATION OF NET PRECIPITATION DATA — BY ELON S. VERRY



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THE AUTHOR

Elon S. Verry is a Forest Hydrologist at the Northern Conifers Laboratory in Grand Rapids, Minnesota. He received his B.S. in forestry in 1965 and his M.S. in water resources in 1967 from the University of Illinois. In 1974 he completed course work for a Ph.D. in the Department of Earth Resources at Colorado State University. He is currently doing forestry research on water yield and quality and the management of waterfowl impoundments.

North Central Forest Experiment Station
John H. Ohman, Director
Forest Service - U.S. Department of Agriculture
Folwell Avenue
St. Paul, Minnesota 55108

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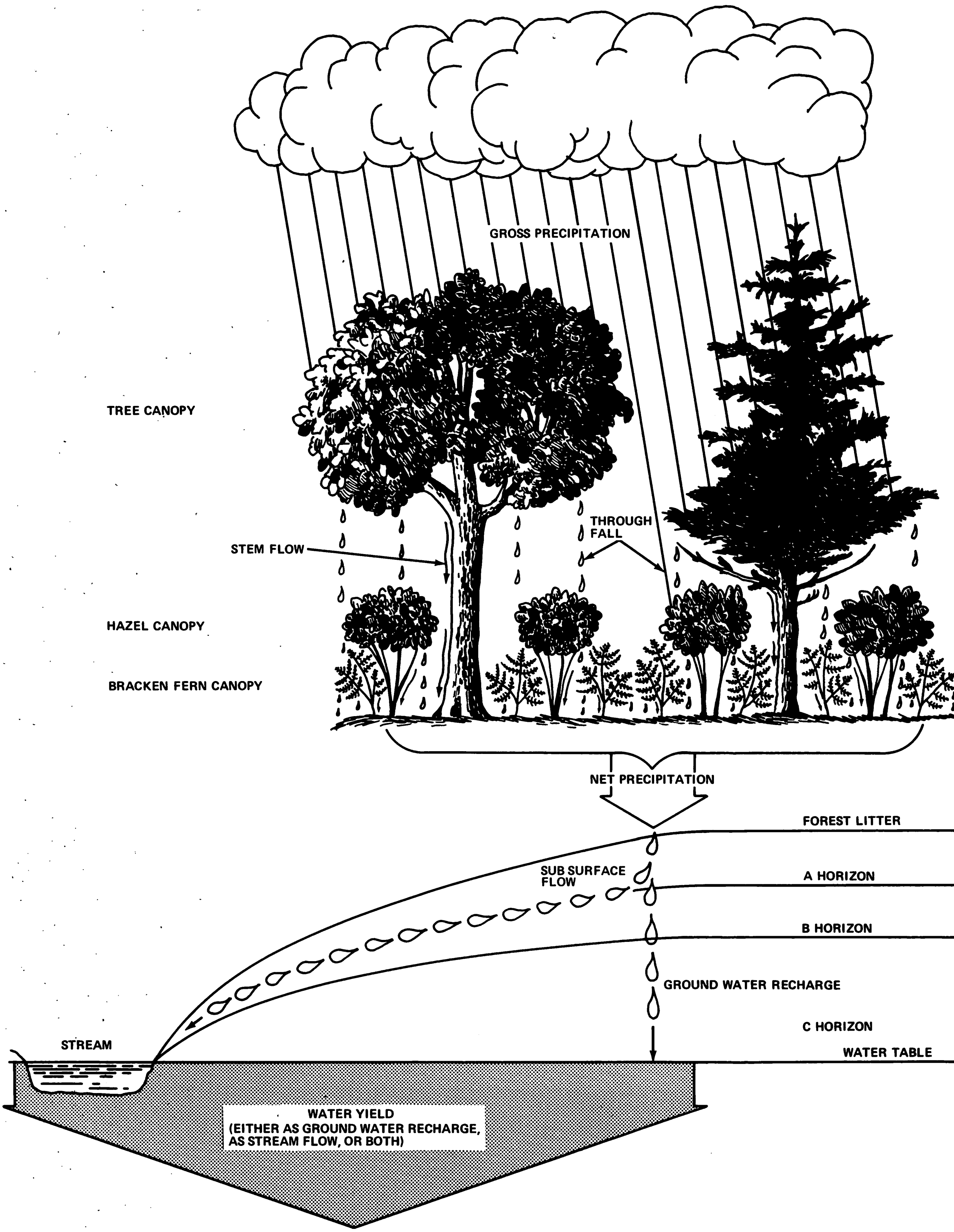

ESTIMATING WATER YIELD DIFFERENCES BETWEEN HARDWOOD AND PINE FORESTS: AN APPLICATION OF NET PRECIPITATION DATA

Elon S. Verry

INTRODUCTION

The impact of different forest types on streamflow or groundwater recharge must be considered in evaluating multiple-use alternatives. The impact of species conversion on streamflow has been directly measured at the Coweeta Experimental Watersheds in North Carolina. However, the use of net precipitation[1] data, with appropriate cautions, provides a practical basis for estimating water yield differences between forest types where long-term streamflow comparisons are not available.

The use of net precipitation differences among hardwood and pine forests as an estimate of water yield differences should not be interpreted as a total explanation of processes affecting water yield. It is only an arbitrary, conservative estimate of species effects on water yield. It does provide a practical working tool with objective values.

This paper presents net precipitation data for stocking levels of one aspen and three red pine forests in north-central Minnesota described in table 1. Net precipitation data for aspen are similar to data for all eastern hardwood forests (Helvey and Patric 1965), and data for red pine are similar to net precipitation data for all eastern pine forests (Helvey 1971). Thus relationships derived in this paper are applicable to other hardwood and pine forests in the northern Lake States.

[1] *See drawing on page ii and the Glossary of terms for definitions.*

Table 1.--*Characteristics of forests to which net precipitation relations were applied*

Forest components	Basal[1] area	Stems	Crown height	Crown coverage	Age	Site index age 50
	m^2/ha	*No./ha*	*m*	*Percent*	*Years*	*m*
Aspen	23.0	1,112	23.2	82	52	22.9
Hazel	--	42,000	2.6	80	--	--
Bracken	--	32,865	--	52	--	--
Red pine	13.8	215	19.8	--	67	16.8
Hazel	--	33,357	2.1	80	--	--
Bracken	--	30,641	--	48	--	--
Red pine	23.0	470	20.4	--	67	16.8
Hazel	--	15,815	2.0	50	--	--
Bracken	--	26,193	--	41	--	--
Red pine	32.1	675	20.7	--	67	16.8
Hazel	--	15,073	1.1	46	--	--
Bracken	--	19,027	--	30	--	--

[1] Basal areas of 13.8, 23.0, and 32.1 m^2/ha correspond to basal areas of 60, 100, and 140 ft^2/acre. See Appendix I, page 6 for other conversion factors.

The assumptions in this paper are many and result from the combination of many separate studies to bear on a single application. As with any modeling approach, the necessary assumptions point up our lack of knowledge or areas of disagreement. Rainfall components are derived from relatively straight forward application of specific studies. However, we assumed seasonal net snowfall to be the maximum snowpack water content. This, of course, is incorrect because it does not account for overwinter melt that may infiltrate the soil or for additions to the snowpack from soil water.

The literature contains many conceptual analyses of snowfall interception (Miller 1964, 1967, Anderson 1970) from which the authors conclude that simple snow tube measurements cannot explain the interception process. In addition, at least two studies have shown that overwinter snowmelt increases soil water and streamflow (Federer 1965, Haupt 1972).

Our data from the Marcell Experimental Forest (Ca. N 47° 32' Lat., 93° 28' W Long.) showed that any overwinter melt from the bottom of the snowpack that does occur is not sufficient to produce shallow subsurface flow let alone streamflow: (1) runoff plots that measure both surface and shallow subsurface flow have never yielded flow over the winter period; and (2) shallow water tables recede slightly over winter even in sealed, perched basins from where there is no streamflow. Furthermore, we have never observed crown drip during this period in north-central Minnesota; a process that Haupt (1972) showed to be a significant source of winter soil water recharge in Idaho.

These observations do not tell us whether or not snowpack water entered the soil to satisfy soil water storage deficits, but they do indicate that it is not sufficient to affect streamflow, or even local subsurface flow. In the severe continental climate of north-central Minnesota, at least, it does appear to give a useful estimate of maximum snowpack water content and the effect of forest types on it.

HISTORICAL PERSPECTIVE

In 1965, Dr. J. Delfs (1967) of Lower Saxony, Germany, proposed a practical assessment of interception data. He stated:

> "Preliminary results suggest that it is chiefly interception which is responsible for the effect of beech and spruce stands on the water regime. ...The beech area discharged over 200 millimeters (mm) more than the spruce area."

This was a bold statement indeed. The concept was met with arguments that interception differences might be balanced by differences in tree transpiration.

Dr. Delfs' proposal gained considerable credence in 1968 when Swank and Miner reported the effect on streamflow of converting a hardwood watershed to white pine. When the white pine trees were only 10 years old, streamflow had decreased by 94 mm. In their first report, they stated:

> "Although results reflect a specific set of . . . conditions, and identical water yield reductions would not be expected elsewhere, the evaporation processes involved are universal. Thus a trend toward reduction in total water yield should also be expected in other regions." (Swank and Miner 1968).

Four years later streamflow had been reduced by 178 mm. Thus, in a second report, they concluded, "...that increased interception loss occurs when hardwood-covered watersheds are converted to white pine, causing significant reductions in streamflow . . . " (Swank, Goebel, and Helvey 1972). These conclusions are further supported in a 15-year summary published by Swank and Douglas in 1974.

An important and practical finding of Swank and Miner's study is that the differences in net precipitation are a conservative estimate of differences expected in streamflow. Streamflow differences may in fact be greater because transpiration by pines during leafless periods is probably greater than that of hardwoods (Swank, Goebel, and Helvey 1972). These concepts should even apply to other areas in humid regions.

Swank, Goebel, and Helvey (1972) applied this concept to assess the impact of large scale conifer plantations on streamflow throughout the southeastern United States. They used interception studies for hardwoods developed throughout the eastern United States and interception studies for loblolly pine developed at Clemson, South Carolina. Their estimate of streamflow differences at Clemson is 102 mm (4 inches). However, the absolute amount of interception loss or net precipitation for any given forest is primarily determined by the amount of annual precipitation. Thus differences between hardwood and pine forest net precipitation will be less in dry areas than in wet areas.

In areas where multiple-use decisions dictate pine, lower stocking levels could be maintained to enhance water yield or vice versa. Thinning in pine stands has increased water yield (Urie 1971, Van Der Zell 1970); however, long-term streamflow data are not available to assess how long the effect will last.

Thinnings in hardwood stands have caused small increases in streamflow that, are probably real although they were not statistically significant (Reinhart, Eschner, and Trimble 1963, Douglass and Swank 1972).

APPLICATIONS

The aspen and red pine data are applicable to most areas, but there are conditions where differences in net precipitation may not be realized as differences in water yield. These occur where infiltrated water is evapotranspired before it passes below or away from plant roots; either because (a) plant roots reach to the water table or (b) additional water does not contribute to deep percolation or shallow subsurface flow because it is insufficient to satisfy soil water deficits around macropores.

To determine differences in water yield for a given area of land with total conversion:

A. First obtain your average annual precipitation for the area in question.
B. Enter figure one along the annual gross precipitation scale and proceed upward to intersect the 23 m^2/ha red pine line.
C. From the point of intersection on the red pine line proceed to the left scale and read the intersected value of net precipitation.
D. Repeat the procedure using the aspen line.
E. The difference in net precipitation will increase water yields for red pine-to-aspen conversions and decrease water yields for aspen-to-red pine conversions.

For example, average annual precipitation is 756 mm for the Marcell Experimental Forest in north-central Minnesota. By entering the base of figure 1, we can estimate that net precipitation is 633 mm for the 23 m^2/ha aspen stand 567 mm for the 23 m^2/ha red pine stand: a difference of 66 mm. Therefore, this would mean that water yield would be increased or decreased 35 percent because the average streamflow on the Marcell Experimental Forest is 189 mm.

This same principle can be used for planning purposes on large administrative units (District, Forest, or other large area). For example, a district ranger can use his management plan to list the hectares of conversions scheduled for the future (5, 10 yrs., etc.). He must then take the difference between the proposed total area of hardwood-to-pine conversions and pine-to-hardwood conversions. This difference must be translated to a percentage of the total planning unit area. Then he can:

A. Enter figure 2 along the net percent change scale and proceed upward to intersect the precipitation-runoff regime line nearest to your situation.
B. From the point of intersection on the precipitation-runoff line proceed to the left scale and read the percent change in existing water yield for the <u>entire</u> planning unit.
C. Multiply the decimal percent change in water yield by the existing water yield to calculate the proposed change in water yield.
D. If the total volume of water yield change is desired, multiply the change in water yield by the total area of the planning unit.

If on a planning unit area of 100,000 ha, for example, 2,000 ha are planned for pine-to-hardwood conversion, and 13,000 ha are planned for hardwood-to-pine conversion, then the net percent change

$$\left(\frac{13{,}000 - 2{,}000}{100{,}000}(100)\right)$$

would be 11 percent. If we assume that the average annual precipitation is 700 mm and the average annual runoff is 190 mm for the planning area, we would enter figure 2 at 11 percent (horizontal axis) on line B and find that the percent change in water yield on the entire planning unit is 3.7 (see dotted line). This means that the decrease in annual water yield

$$\left(\frac{(3.7)(190)}{(100)}\right)$$

is approximately 7 mm because the net conversion is from hardwood to pine forests.

The total decrease in water yield volume would be:

(0.007 m)(100,000 Ha)	= 700 ha-m
(700 ha-m)(8.107)	= 5,675 acre-feet
(5,675 acre-feet)(325,851)	= 1.8 x 10^9 gallons

This would approximate the annual needs of a community of 50,000 assuming total storage (based on a per capita consumption of 100 gallons per day).

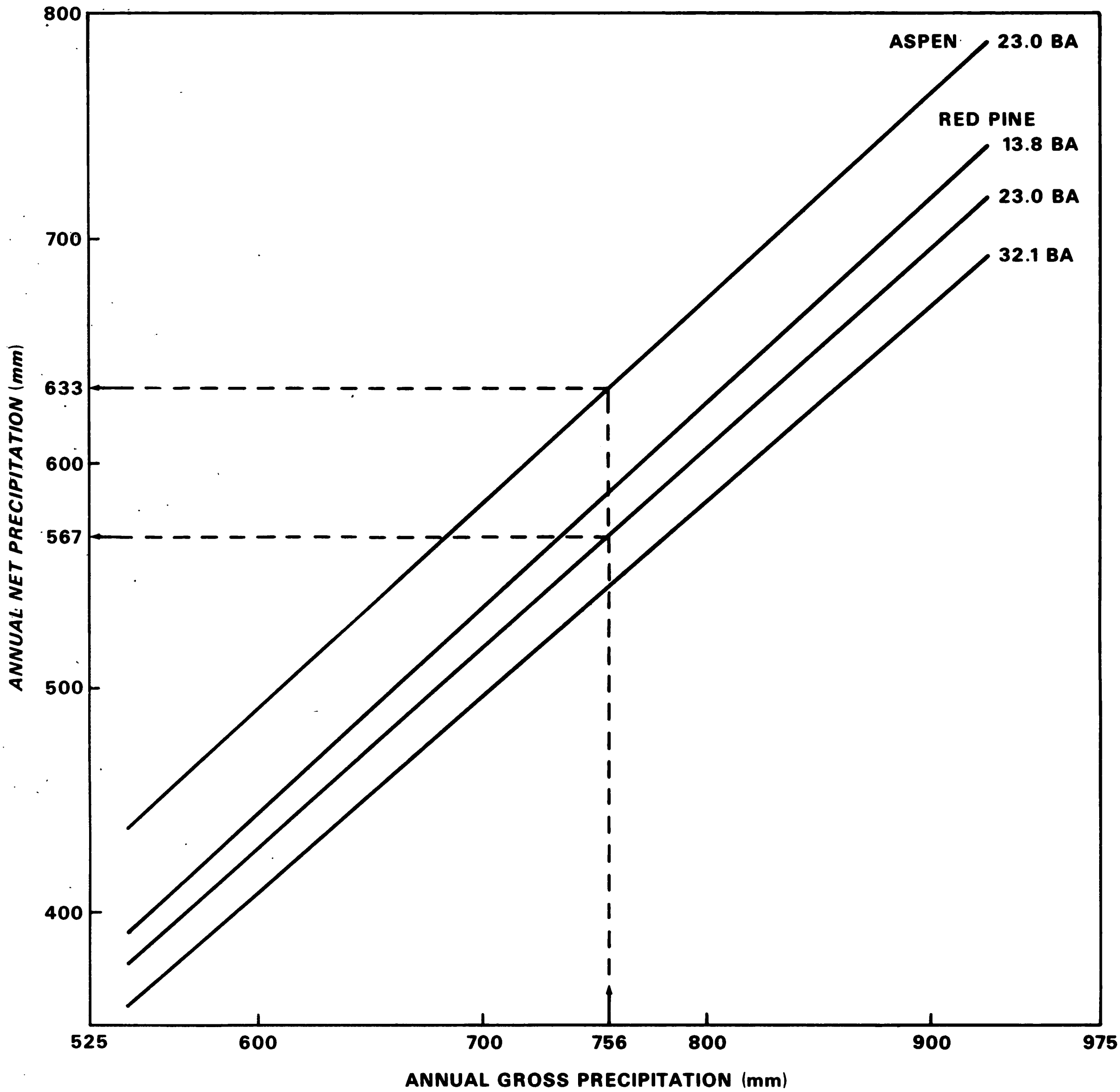

Figure 1.--*The relation between net and gross annual precipitation for aspen and red pine forest (23 and 13.8, 23, 32.1 m^2/ha basal area respectively).*

The four precipitation-runoff lines in figure 2 were taken from precipitation and runoff graphs for the northern Lake States. Lines for a specific area in the northern Lake States can be easily developed using local data as follows:

A. Determine the difference in net precipitation (Δ NP)[2] between aspen and red pine forests following the five steps shown for determining differences on a given area of land with total conversion (see page 3).

B. Obtain your average annual runoff (Q).

C. Assuming a 100 percent conversion, calculate the percent change in existing water yield on the entire planning unit area as follows:

$$\frac{\Delta NP}{Q}(100) = \% \text{ change } (\Delta Q)$$

[2] *See Appendix II, page 7, for further definitions of the symbols.*

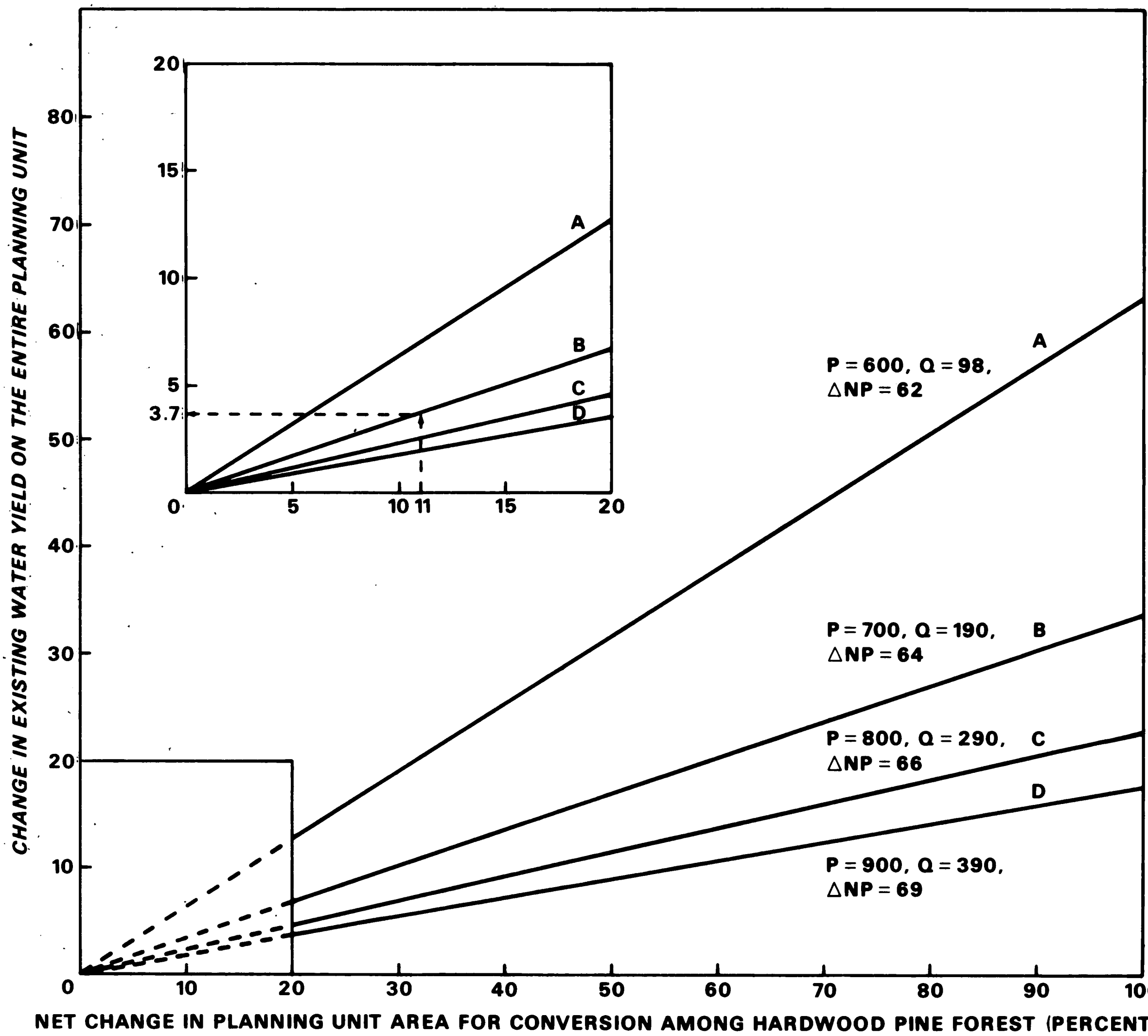

Figure 2.--*The relation between net percent change in planning unit area and percent change in existing water yield for hardwood-pine conversions at four levels of precipitation (P), water yield (Q), and differences in net precipitation (Δ NP).*

D. Draw your figure 2 line by plotting the point X = 100; Y = ΔQ and drawing a line from there through the origin.

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APPENDIX I--GLOSSARY OF TERMS

Gross precipitation (P): The amount of rain or snow falling above the forest as measured in small forest openings.

Interception loss: The amount of water retained on plants and subsequently evaporated.

Net precipitation (Net P): The amount of water falling on (rain) or accumulating on (snow) the litter. The end of snow accumulation is defined as the time when water content in the snowpak is maximum.

Stemflow (S): The amount of rain that reaches the ground by flowing down plant stems.

Throughfall (T): The amount of rain passing through a plane just below the identified canopy exclusive of stemflow. It is adjusted to reflect the density of the canopy in question. Adjustments are made on a basal area basis for trees and a percent crown coverage basis for hazel and bracken fern.

Water Yield: The amount of water measured as streamflow or groundwater recharge.

All precipitation components are expressed on an equivalent area-depth basis, in millimeters (mm).

Conversion Factors

(inches)(25.4) = mm
(feet)(0.3048) = m
(acres)(0.4047) = ha
$(ft^2/acre)(0.22957) = m^2/ha$
(millimeters)(0.03937) = in.
(meters)(3.2808) = ft.
(hectares)(2.47104) = acres
$(m^2/ha)(4.35603) = ft^2/acre$

APPENDIX II--DERIVATION OF APPLICATION PROCEDURES

The following equation will illustrate the derivation of application procedures for evaluating large planning units:

$$\Delta Q = \frac{Q_n - Q}{Q} (100)$$

or

$$\Delta Q = \frac{\left(\frac{\Delta A}{T} \times 100\right)(q_n) + \left(100 - \frac{\Delta A}{T} \times 100\right)(Q)}{Q} - [100]$$

where:

T = total planning unit area
H_e = existing hardwood area
H_d = desired hardwood area
$\Delta A = |H_e - H_d|$ = absolute value of net area changed from hardwood to pine or vice versa
Q = existing water yield (area basis)
ΔQ = percent change in existing water yield
ΔNP = difference in net precipitation for hardwood and pine forests on the planning unit
$q_n = Q - \Delta NP$ = water yield from converted area (subtract ΔNP for hardwood to pine conversions; add for the converse).
$U = T - \Delta A$ = net area on planning unit which is unchanged
Q_n = the new estimate of water yield on the entire planning unit.

$$Q_n = \frac{(\Delta A)(q_n) + (U)(Q)}{T}$$

Other data can be utilized in the foregoing procedure by simply substituting for the ΔNP term. For instance, differences in soil water depletion, streamflow response to clearcutting, and actual streamflow following conversions could be utilized if available.

APPENDIX III--DOCUMENTATION FOR ASPEN AND RED PINE EQUATIONS

Two basic equation forms were used; one for net storm rainfall and one for net seasonal snowfall. The general equation for individual rain storms was:

$$\text{Net P} = AT_B + BT_H + CT_T + S_B + S_H + S_T \qquad (1)$$

where: Net P = Net storm precipitation (rainfall) reaching the ground

T_B = Throughfall under bracken fern
T_H = Throughfall under hazel
T_T = Throughfall under trees
A, B, C = Coefficients reflecting the percent coverage of holes in successively lower canopies
S_B = Stemflow down bracken fern stems
S_H = Stemflow down hazel stems
S_T = Stemflow down tree stems

All components are expressed on a mm basis. The basic form was modified for dormant season rainfall by deleting the bracken fern components. The dormant season was defined annually as including two periods: October 1 until the first snow and the last snow until May 15.

The tree throughfall and stemflow values were derived using the equations in tables 2, 3, and 4. The hazel T and S values are derived from equations using tree throughfall as the independent variable; and the bracken fern T and S values are derived from equations using hazel throughfall as the independent variable. Exceptions to this progression are sometimes used to take advantage of various independent studies. Where available each equation has the variance ($S^2_{y \cdot x}$) and number of data sets going into it (N) listed.

Annual net snowfall was calculated using only one equation for the entire snow year. The general equation is:

$$MP = A + BP \qquad (2)$$

where:

MP = The maximum water content occurring in the snowpack for a given year,
P = Standard snow gage precipitation (shielded, ethylene glycol and oil charged standard U.S. Weather Bureau snow gages) for the period between the first snowfall to stay on the ground and the time of maximum snowpack water content.
A, B = Coefficients in a first degree polynomial.

Table 2.--*Stemflow, throughfall, and net precipitation equations for a 23 BA aspen, hazel, bracken fern forest, growing season conditions*
(In mm)

Component	Equation[1]	$S^2_{y \cdot x}$	N[3]	Source
Aspen stemflow	$(S_A) = -0.051 + 0.040\ P$	0.0017	27	(4)
Aspen-hazel throughfall	$(T_{A-H}) = -1.041 + 0.858\ P$	.0152	28	(4)
Hazel stemflow	$(S_H) = (4.2)(0.001T_A^{1.451})(2.6)^{(2.06\ T_A^{-0.182})}$	-	36	Clements 1971
Bracken fern stemflow	$(S_B) = (3.2865)(0.034)(T_{A-H})^{(0.873)}$	.021[2]	8	Clements 1971
Bracken fern throughfall	$(T_B) = -0.250 + 0.76\ T_{A-H}$	.109	8	Clements 1971
Net precipitation	$(\text{Net P}) = 0.52\ T_B + 0.48\ T_{A-H} + S_A + S_H + S_B$	-	-	-

[1] P=gross rainfall; $T_A = T_{A-H} + 0.058\ P + 0.23$ calculated from Clements 1971; 4.2 amd 3.2865 = No. stems per ha ÷ 10,000; 2.6 = mean height of codominant hazel stems (in m); 0.52 = decimal percent of bracken fern crown coverage, 0.48 = decimal percent of "holes" in bracken fern canopy.

[2] $S^2_{y.x}$ refers to single stem equation (delete area factor of 3.2865).

[3] N = number of data sets in each equation

[4] Verry, unpublished data. (A 1969 and 1970 interception study at the Marcell Experimental Forest in the aspen stand described in table 1. Stemflow was measured by area on two 0.016 ha plots with 12 trees each. Throughfall measured in 25 randomly located rain gages setting on the ground beneath the tree and hazel canopies.)

Table 3.--*Stemflow, throughfall, and net precipitation equations for a 23 BA aspen, hazel forest, dormant season conditions*
(In mm)

Component	Equation	$S^2_{y \cdot x}$	N	Source
Aspen stemflow[1]	$(S_A) = -0.051 + (0.040)(1.5)\ P$	-	-	Verry, Helvey & Patric 1965[1]
Aspen throughfall	$(T_A) = -0.381 + 0.914\ P$	-	-	Helvey & Patric 1965
Hazel stemflow	$(S_H) = (4.2)(0.001T_A^{1.451})(2.6)^{(2.06\ T_A^{-0.182})}$	-	8	Clements[2]
Hazel throughfall[3]	$(T_H) = -0.13 + 0.95\ T_A$	-	-	Helvey & Patric 1965
Net precipitation[4]	$(\text{Net P}) = 0.20\ T_A + 0.80\ T_H + S_A + S_H$	-	-	-

[1] Slope term multiplied by 1.5

[2] Based on a few measurements there is no difference between dormant and growing season stemflow relations (Personal Communication with Dr. John R. Clements, October 1972).

[3] Percent increase terms of 1.515 and 1.0111 are applied to slope and intercept terms respectively; after relations for hardwoods.

[4] 0.80 = decimal percent of hazel crown coverage and 0.20 = decimal percent of "holes."

Table 4.--*Stemflow, throughfall, and net precipitation equations for a 23 BA red pine, hazel, bracken fern forest, growing season conditions*

Component	: Equation[1]	: $S^2_{y \cdot x}$	: N	: Source
Red pine stemflow	$(S_R) = -0.076 + 0.02\ P$	0.003	80	Rogerson & Byrnes 1968
Red pine throughfall	$(T_R) = -1.02934 - 0.00422\ P\ (23) + 0.97950\ P$	.065	80	Rogerson 1967[4]
Hazel stemflow	$(S_H) = (1.5815)(0.001\ T_R^{1.451})(2.0)^{(2.06\ T_R^{-0.182})}$	-	36	Clements 1971
Hazel throughfall	$(T_H) = 0.50\ T_R + 0.50\ (-0.27 + 0.94\ T_R)$	.303[2]	27	Clements 1971
Bracken fern stemflow	$(S_B) = (2.6193)(0.034)(T_H)^{(0.873)}$	.021[3]	8	Clements 1971
Bracken fern throughfall	$(T_B) = -0.250 + 0.76\ T_R$	.109	8	Clements 1971
Net precipitation	$(\text{Net P}) = 0.41\ T_B + 0.59\ T_R + S_R + S_H + S_B$	-	-	-

[1] P = gross rainfall; 23 = BA red pine (m^2/ha); 1.5815 and 2.6193 = No. stems per ha ÷ 10,000; 2.0 = mean height of codominant hazel stems (in m); 0.50 = decimal percentage of hazel crown coverage and "holes" in hazel crown; 0.41 = decimal percentage of bracken fern crown coverage; 0.59 = decimal percentage of holes in bracken fern canopy.

[2] Refers to equation in parenthesis only.

[3] Refers to single stem equation (delete area factor of 2.6193).

[4] Loblolly pine equation with .563 subtracted from intercept term. 0.563 derived from comparison of red pine and loblolly pine equations.

Specific equations that were used to calculate net snowfall under each forest type are shown in table 5.

Table 5.--*Seasonal net snowfall equations* (In mm)

Forest	: Maximum water content : equation[1]	: $S^2_{y \cdot x}$	: N	: Source
24.3 BA Aspen	MP = 2.134 + 0.900 P	2.134	39	([2])
34.4 BA Jack pine	MP = -9.627 + 0.879 P	7.378	10	([2])
32.1 BA Red pine	MP = -9.627 + 0.879 P	-	-	([3])
23 BA Red pine	MP = -7.087 + 0.879 P	-	-	([3])
13.8 BA Red pine	MP = -4.547 + 0.879 P	-	-	([3])

[1] MP = The maximum water content occurring in the snowpack for a given year. P = The sum of standard snowgage precipitation for the period between the time of the first snowfall to stay on the ground and the time of maximum snowpack water content.

[2] Verry, unpublished data. Based on 10 years of Mt. Rose snowtube measurements at 78 aspen points and 10 jack pine points on the Marcell Experimental Forest.

[3] Bay, R. R., and D. H. Boelter, unpublished data. Exploration study of snow accumulation, snow disappearance, soil freezing and moisture regime in several types of northern Lake States forests. Final Progress Rpt, 1960, on file at the Northern Conifers Laboratory, Grand Rapids, Minnesota. Two years of maximum snowpack data under three stocking levels of red pine were similar to our jack pine data. Therefore we used our jack pine equations for red pine with appropriate changes in the intercept terms for the three stocking levels. Red pine data from Dils and Arend (1956) for snow depths showed a similar trend. These equations are also within the data range for snowpack water content given by Hansen (1969) at the 61 mm P level.

To obtain the annual net precipitation, the following equation was used:

$$NP = \sum_{i=1}^{n} \text{net } P_i + MP \qquad (3)$$

where:

net P_i = the amount of net precipitation per rainstorm

n = the number of rainstorms per year

MP = the total net snowfall

A year was defined as beginning on April 1 and ending on March 31. A rainstorm was defined as a rainfall event separated by at least 6 hours from another rainfall event. All of the net precipitation equations were applied to actual rain and snow records from the Marcell Experimental Forest in north central Minnesota (Ca. 47° 32'N, 93° 28'W). High, average, and low rainfall years were combined with high, average, and low snowfall years, respectively, to avoid possible confounding of forest comparisons. The resulting range of annual precipitation was identical to the measured range of annual precipitation. There were periods of 2 to 4 weeks during each year when snow fell after the snowpack began to melt. I assumed that these snowfalls would be followed by above freezing temperatures and that net precipitation could be calculated best using the net storm rainfall equations.

Equations for dormant season hazel throughfall and stemflow in the red pine stand are identical to those of the aspen stand except that T_R replaces T_A and stems per hectare values are changed appropriately (table 1). The net storm precipitation equation for dormant season red pine stands is similar to that of table 3 except T_R replaces T_A and the crown coverage weighting factors are 0.50 and 0.50.

Growing and dormant season rainfall T, S and Net P equations for 13.8 and 32.1 BA red pine forests are identical to those for 23 BA red pine except as modified by basal area, stems per acre, and percent crown coverage.

All the equations for net rainfall components are applicable for gross rainstorms of 2-50 mm except the equation for aspen stem flow during the dormant season which is applicable for 2-25 mm. Equations for maximum snowpack water content are applicable for seasonal gross precipitation from 60 to 220 mm.

Many studies in the literature do not list variances, data sets or sum of "independent variable" deviations. Therefore, a straightforward variance calculation for annual net precipitation totals is impossible. Other fundamental gaps in data, such as additional water losses between site and user makes a statistical treatment of secondary importance.

The net storm rainfall equations were used with actual growing season and dormant season rainfall data and summed to calculate the annual distribution of rainfall in the aspen and red pine forests. Data for an average rainfall year are shown in table 6.

The net storm rainfall equations were added to net seasonal snowfall equations for low, average and high precipitation years to give annual estimates of net precipitation (table 7). The total net precipitation data for aspen and red pine forests were used to construct the lines in figure 1.

Table 6.--*Distribution of rain in four forests for an average precipitation year*
(In mm)

Rainfall season and forest	Stem-flow tree	Stem-flow hazel	Stem-flow bracken	Through-fall tree	Through-fall hazel	Through-fall bracken	Net precipitation
Average growing season rain (460 mm)							
23 BA aspen	16	19	28	---	348	300	362
13.8 BA red pine	6	11	26	377	350	306	349
23 BA red pine	6	5	22	359	343	306	339
32.1 BA red pine	6	2	15	342	328	301	325
Average dormant season rain (175 mm)							
23 BA aspen	9	7	--	149	140	---	156
13.8 BA red pine	2	4	--	136	128	---	134
23 BA red pine	2	2	--	129	125	---	128
32.1 BA red pine	2	1	--	123	119	---	121
Average growing and dormant season rain (635 mm)							

Table 7.—*Net precipitation under four forests in north-central Minnesota for low, average, and high precipitation years*

Precipitation			No. of storms	Gross precip.	23 BA aspen	13.8 BA red pine	23 BA red pine	32.1 BA red pine
					LOW			
Rain	GS[1]	mm	41	272.3	200.3	190.8	185.9	178.1
		%		(100)	(73.5)	(70.1)	(68.3)	(65.4)
	DS[2]	mm	39	207.8	182.2	150.4	144.2	136.2
		%		(100)	(87.7)	(72.4)	(69.4)	(65.6)
Subtotal		mm	80	480.1	382.5	341.2	330.1	314.3
		%		(100)	(79.7)	(71.1)	(68.7)	(65.5)
Snow		mm	25	61.0	56.9	49.3	46.7	44.2
		%		(100)	(93.3)	(80.8)	(76.6)	(72.5)
Total		mm	105	541.1	439.4	390.5	376.8	358.5
		%		(100)	(81.2)	(72.2)	(69.6)	(66.2)
					AVERAGE			
Rain	GS	mm	47	459.5	362.4	349.2	338.8	325.1
		%		(100)	(78.9)	(76.0)	(73.7)	(70.8)
	DS	mm	27	175.0	156.1	133.9	128.2	121.3
		%		(100)	(89.2)	(76.5)	(73.3)	(69.3)
Subtotal		mm	74	634.5	518.5	483.1	467.0	446.4
		%		(100)	(81.7)	(76.1)	(73.6)	(70.4)
Snow		mm	34	121.9	111.8	102.9	100.3	97.8
		%		(100)	(91.7)	(84.4)	(82.3)	(80.2)
Total		mm	108	756.4	630.3	586.0	567.3	544.2
		%		(100)	(83.3)	(77.5)	(75.0)	(71.9)
					HIGH			
Rain	GS	mm	45	477.5	381.0	367.0	355.6	341.3
		%		(100)	(79.8)	(76.8)	(74.5)	(71.5)
	DS	mm	26	241.0	221.0	197.0	188.2	178.3
		%		(100)	(91.7)	(81.7)	(78.1)	(74.0)
Subtotal		mm	71	718.5	602.0	564.0	543.8	519.6
		%		(100)	(83.8)	(78.5)	(75.7)	(72.3)
Snow		mm	33	208.3	189.5	178.8	176.3	173.7
		%		(100)	(91.0)	(85.5)	(84.6)	(83.4)
Total		mm	104	926.8	791.5	742.8	720.1	693.3
		%		(100)	(85.4)	(80.1)	(77.7)	(74.8)

[1]GS = Growing season
[2]DS = Dormant season

APPENDIX IV--DOCUMENTATION FOR BLACK SPRUCE EQUATIONS

Stemflow and throughfall were measured in two black spruce stands on the Marcell Experimental Forest in 1969 and 1970. In these stands, which grew on organic soils, there were not any tall shrubs or forbs.

The 73-year-old stand had a total basal area of 30.1 m^2/ha on 3,029 stems. The 62-year-old stand had a total basal area of 26.2 m^2/ha on 8,411 stems. Average dominant height in the older stand was 15 m and 11 m in the younger stand. Crown coverage in both stands was approximately 68 percent.

Stemflow was measured on a 0.016 ha plot in each stand from 12 trees. Throughfall was measured in 25 randomly located rain gages. There was no difference in data between the two stands ($P \geq 0.10$).

$$S_{BS} = -0.004 + 0.001 \text{ P mm} \quad S^2_{y \cdot x} = 0.0004 \text{ mm}$$

$$N = 47$$

$$T_{BS} = -1.600 + 0.934 \text{ mm} \quad S^2_{y.x} = 0.025 \text{ mm}$$

$$N = 78$$

where:

S_{BS} = black spruce stemflow
P = gross rainfall
T_{BS} = black spruce throughfall

A seasonal net snowfall equation was derived from 10 years of Mt. Rose snowtube measurements at 39 points under six stands on the Marcell Experimental Forest. The six stands averaged 23 m^2/ha of total basal area on 1,860 stems. Average dominant height was 13.4 m, average age 90 years, and average crown coverage 51 percent.

The seasonal net snowfall equation was:

$$MP = -1.448 + 0.782 \text{ P mm} \quad S^2_{y.x} = 2.397$$

$$N = 19$$

where:

MP = the maximum water content occurring in the snowpack
P = the sum of standard snowgage precipitation

The black spruce equations above were solved for low, average and high precipitation year to give the net precipitation values in table 8. Stemflow values were only a trace on an area basis; therefore, the net precipitation values in table 8 are simply black spruce throughfall. These values are similar to the red pine values without shrub and bracken fern components. Thus, they may be applicable in evaluating conversions on uplands where black spruce stands have a shrub component.

Table 8.--*Net precipitation under black spruce on organic soil with no tall shrubs or forbs*

(In mm)

Precipitation component	Low year: Gross	Low year: Net	Average Year: Gross	Average Year: Net	High Year: Gross	High Year: Net
Rain	480.1	335.9	634.5	488.2	718.5	568.5
Snow	61.0	46.5	121.9	94.0	208.3	161.5
Total	541.1	382.4	756.4	582.2	926.8	730.0

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