REQUIRED ACCURACY OF INPUT DATA FOR WRENSS TO DETERMINE SILVICULTURAL TREATMENT EFFECTS ON ANNUAL WATER YIELD

by

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INTRODUCTION

As the human population and associated consumer needs increase, so does the demand for water. Water resources are finite, and sources of new water are continually being sought. Timber harvesting schedules intended to increase water yield are becoming incorporated into land management plans. Evaluations of the effects of these schedules on water yield are frequently made by using the hydrology models in WRENSS (Water Resources Evaluation of Non-point Silvicultural Sources), (U.S. Forest Service, 1980).

The increased usage of WRENSS (specifically the hydrologic model, referred to as WATBAL), has become an integral part of many land management planning processes. The availability of this model in a microcomputer version which emulates the original model has increased the usage. This paper is not a criticism of the WATBAL model, but rather a sensitivity analysis of input parameters. Specific data requirements and their needed level of accuracy are identified to help model users get the best estimate of the effects of timber harvesting schedules or other vegetation removal, i.e. fire, on annual water yield.

The hydrologic model for regions dominated by rainfall differs from the model for regions dominated by snowfall. WRENSS hydrology provides guidelines for model selection under these different precipitation regimes. The PROSPER model (Goldstein and Mankin, 1972) is applied for simulations in the rain dominated regime (usually below 1250m elevation). Snowpack development is significant above 1250m, and the WATBAL model (Leaf and Brink, 1975) is applied for simulations in the snow dominated regime.

The WRENSS handbook (U.S. Forest Service, 1980) contains a hydrologic procedure for estimating the increase in water yield following silvicultural treatments. The increased annual water yield is obtained from the concomitant decrease in forest vegetation evapotranspiration and interception.

The difference in evapotranspiration between cut and uncut forested watershed is used to approximate how much more water one can expect from that watershed. Evapotranspiration and interception are the only hydrologic process that can be managed with forestry practices. Thus management prescriptions to increase water yield are designed to maximize the reduction in evapotranspiration and secondarily maximize snowpack accumulation. The physical configuration of the watershed as well as operational constraints determine the opportunities for increasing water yield by silvicultural treatments.

Before being modified for WRENSS, WATBAL was data intensive, requiring daily precipitation and maximum and minimum temperatures (Leaf and Brink, 1975). These input requirements have been simplified in WATBAL by requiring only seasonal precipitation data.

The WATBAL 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 have a watershed storage function. Thus calculated water yield is equal to precipitation minus the calculated evapotranspiration, with storage constant.

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WATBAL calculates evapotranspiration by season, and seasonal dates can vary by region. The chief purpose for distinguishing among seasons is to isolate winter (the period of snowpack development and melt) from the other seasons. For the western portions of Washington and Oregon, WATBAL further breaks winter into two sub-seasons.

A calculated change in generated water yield from one or more years may not be directly verifiable as a change in measured water yield because changes in watershed storage are unknown (Swanson, 1987). The water yield estimate is only accurate when the precipitation data are accurate and there is no change in watershed storage. Zero change in watershed storage might best be evaluated over several years record.

WATBAL was designed to give estimates of seasonal evapotranspiration from seasonal precipitation data. Seasonal water yield estimates are calculated, but should not be used separately, particularly given the discussion on watershed storage. Only annual water yield estimates were used in this analysis and model users are encouraged to do the same.

The WRENSS models extrapolate results from experimental watersheds to other basins in similar hydrologic regions, but site specific conditions are not modelled. It should be recognized WRENSS calculates water available for streamflow,not the actual streamflow, i.e., it does no route nor show increases in streamflow gained from treatments at the site level. Finally, model results are not intended to predict absolute amounts of runoff but rather to give good estimates of the differences that can be expected between baseline and post treatment conditions.

The WRENSS model requires input data on basin physiography, seasonal precipitation, vegetation and treatment prescriptions. A study of the model's sensitivity to input parameters will not only provide insight into its behavior but also into the accuracy with which each parameter must be estimated.

INPUT PARAMETERS

Precipitation

Differences between WATBAL estimated and measured changes in yield are not particularly affected by the precipitation data used, as long as the data are from the same vicinity. (Swanson, 1987). Five to 10 year averages or precipitation from the years with the highest and lowest annual streamflow had little effect on estimated changes in annual water yield (Swanson and Bernier, 1986). The seasonal distribution of precipitation has an effect on water yield, but annual water yields should be the only output value used.

Forest Opening

WATBAL requires the forest opening dimensions be parallel to the prevailing wind direction, if unknown the opening area is considered as having a square shape (Bernier, 1986). The treated area is calculated as a portion of the entire watershed. Treated areas are categorized by topographic aspect classes, east-west, north, or south. Forest openings are measured as multiples of the average height (H) of the surrounding forest.

Wind Speed

The windiness of a site has a marked effect on snow evaporation. If wind speeds are generally less than 1m/sec in the winter and spring, snow evaporation (sublimation) can be ignored (Swanson, 1987). Wind speed estimates can be used as brackets to determine water yield changes and on-site measurements determined later for site-specific response. Specific effects of wind speed and area opening are presented later.

Seasonal Evapotranspiration

Energy availability strongly controls snow processes. WATBAL addresses this factor by determining seasonal evapotranspiration by energy aspect. South aspects have the greatest energy availability and therefore the highest evapotranspiration in any season. North aspects have the lowest energy availability and east-west aspects are intermediate.

WATBAL also expresses seasonal evapotranspiration as a function of seasonal precipitation. Simulated evapotranspiration is strongly precipitation dependent at low precipitation levels, except in the early and late winter seasons when precipitation is never limiting.

Watershed Storage

The microcomputer version of WATBAL does not allow the user to calculate changes in storage. Because it contains no provision for estimating storage or storage changes, it cannot be used to estimate the amount of water present in a stream channel at any given time or place (Swanson, 1987). One should not expect either the change in yield (or the annual water yield) to exactly match that actually measured. Year-to-year variation in water yield should be expected, especially in watersheds with variable soil moisture storage.

METHODS

Baseline physiographic, vegetative, and climatic information were summarized (Table 1). Forested areas were considered to have equal amounts of Spruce-Fir (*Picea engelmanni-Abies lasiocarpa*) and Lodgepole Pine (*Pinus contorta*). Existing maximum stand basal areas were averaged for the entire basin. Alpine zones occurred on east-west aspects and were represented by spruce-fir vegetation with a stand basal area of zero. Precipitation was assumed to fall uniformly over the watershed. Response for all tests was measured as annual streamflow in millimeters.

Table 1

BASELINE DATA USED FOR ST. LOUIS CREEK FOR WRENSS SENSITIVITY ANALYSIS

Watershed: St. Louis Creek (includes FEF)

Watershed Area: 85.94 sq.km.

Hydrologic Region: 4

Average Annual Precipitation: 737mm

Average Annual Water Yield: 321mm

RESULTS

Area

Unit areas are not important in either WRENSS model, since precipitation, evapotranspiration, and streamflow are assumed to be distributed uniformly over the watershed. The area function does provide a means of accounting between units.

Precipitation

Approximately 220mm of precipitation were required before streamflow occurred (Figure 1). Streamflow increased with increased annual precipitation. Precipitation values over 700 mm/year increased streamflow at a 1:1 ratio, suggesting evapotranspiration was energy limited.

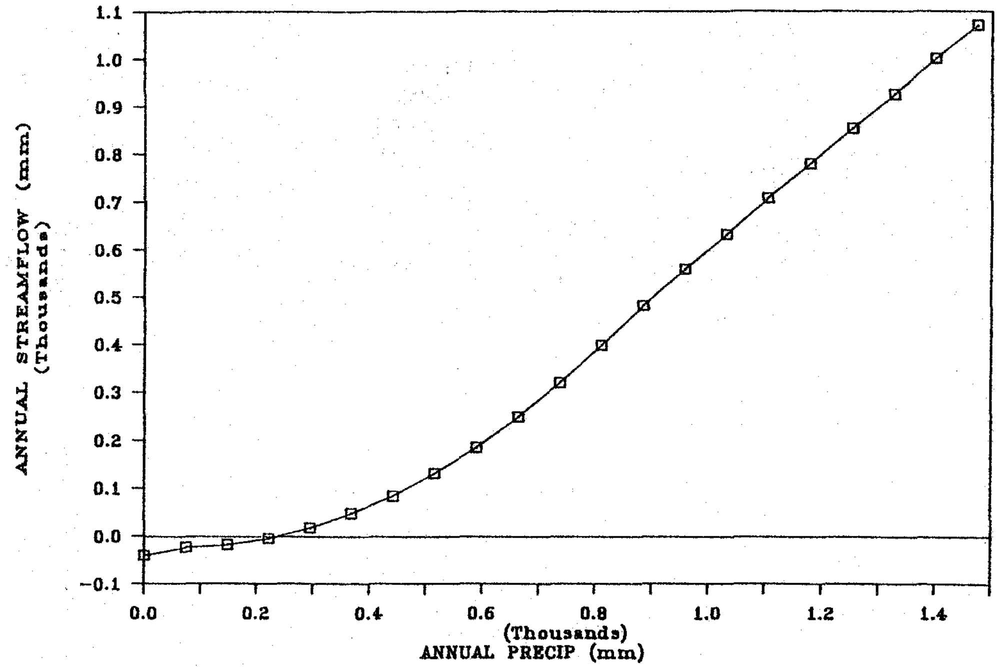

Figure 1. Change in streamflow with change in annual precipitation. Seasonal precipitation changes incremented uniformly.

Streamflow as affected by aspect and precipitation was also evaluated (Figure 2). Predicted annual streamflow for basins with a single aspect was calculated with increasing precipitation. South aspects required more precipitation than other aspects before streamflow initiation. This is accordant with the expected higher potential evapotranspiration on south aspects. However, north aspects required more precipitation than east-west aspects which is contrary to the potential evapotranspiration argument, since north slopes have less potential evapotranspiration than east-west or south slopes. Annual streamflow from basins with east-west aspects started at approximately 120mm with only 85mm precipitation. Streamflow increased at a 1:1 ratio for all aspects once precipitation was greater than 750mm.

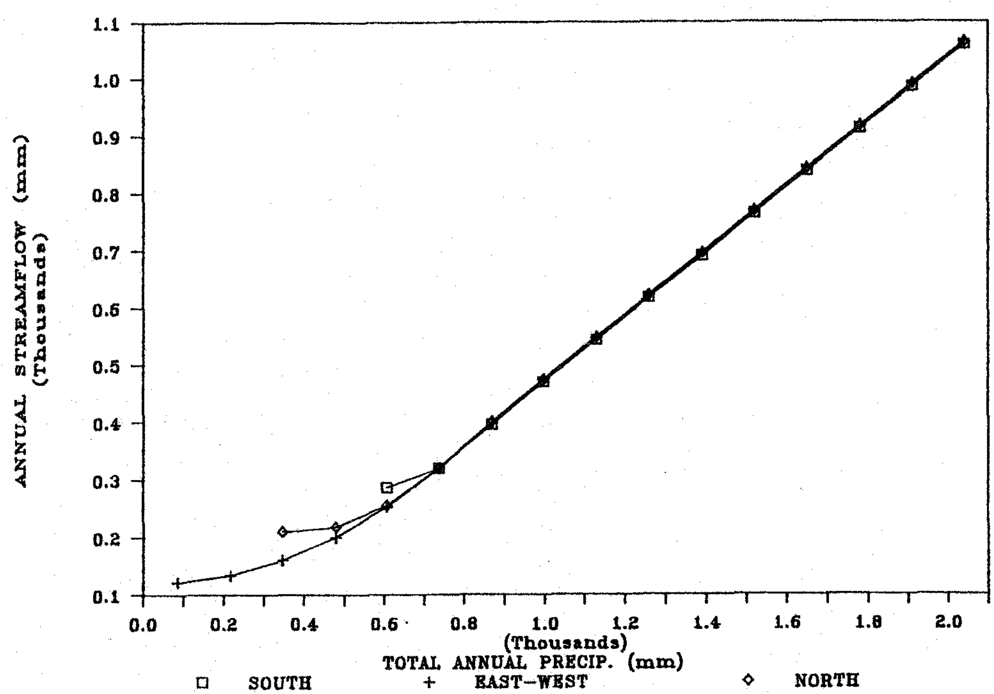

Figure 2. Change in streamflow with change in precipitation by each aspect class.

Forest Stand Characteristics

Streamflow as a function of tree species (and hence evapotranspiration rates) and precipitation showed no differences between tree species. A specific species may not be present over the entire range of precipitation values given, nonetheless, streamflow is influenced by precipitation depth, not tree species present.

Streamflow was minimized or evapotranspiration maximized at $20 m^2/ha$ for WATBAL (Figure 3). Streamflow decreased as the forest stand basal area increased from 0 to $20 m^2/ha$. Evapotranspiration was constant from 20 to $50 m^2/ha$.

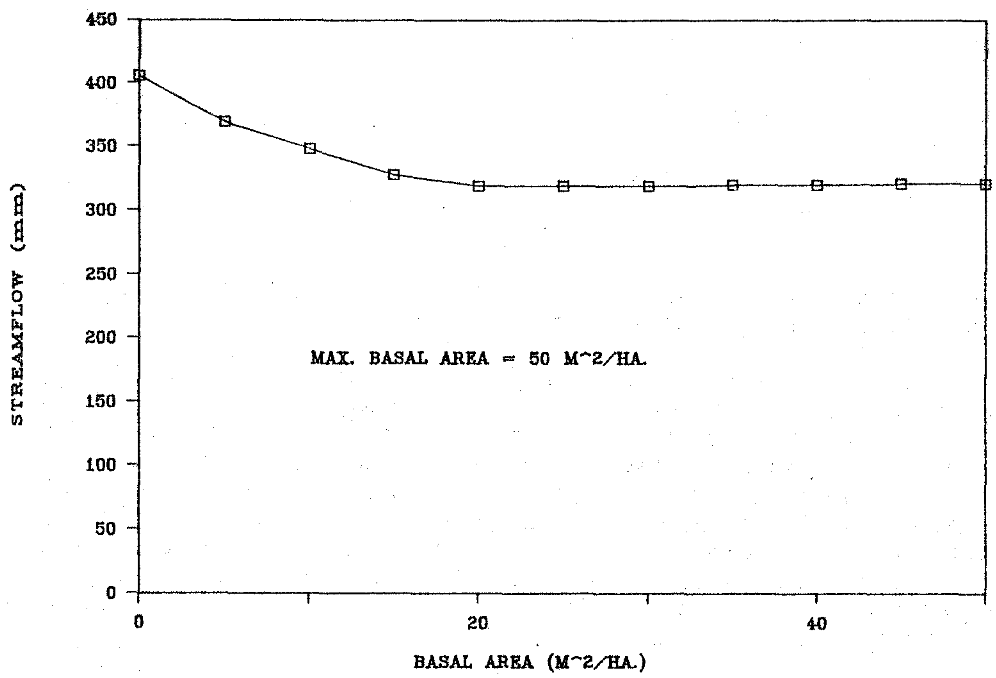

Figure 3. Change in streamflow with change in existing basal area.

Forest Opening

The WATBAL model was run for 3 different wind speeds with 4 different size openings. The opening was considered square shaped. A wind speed of 0m/sec only slightly decreased the water yield from openings of 3H to 15H (Figure 4). A wind speed of 1m/sec decreased the increased annual water yield (Figure 5) as compared to 0m/sec, but annual water yields still increased. A wind speed of 5m/sec tended to decrease annual streamflow, once the opening was above 12H (Figure 6), where H is the average tree height surrounding the opening.

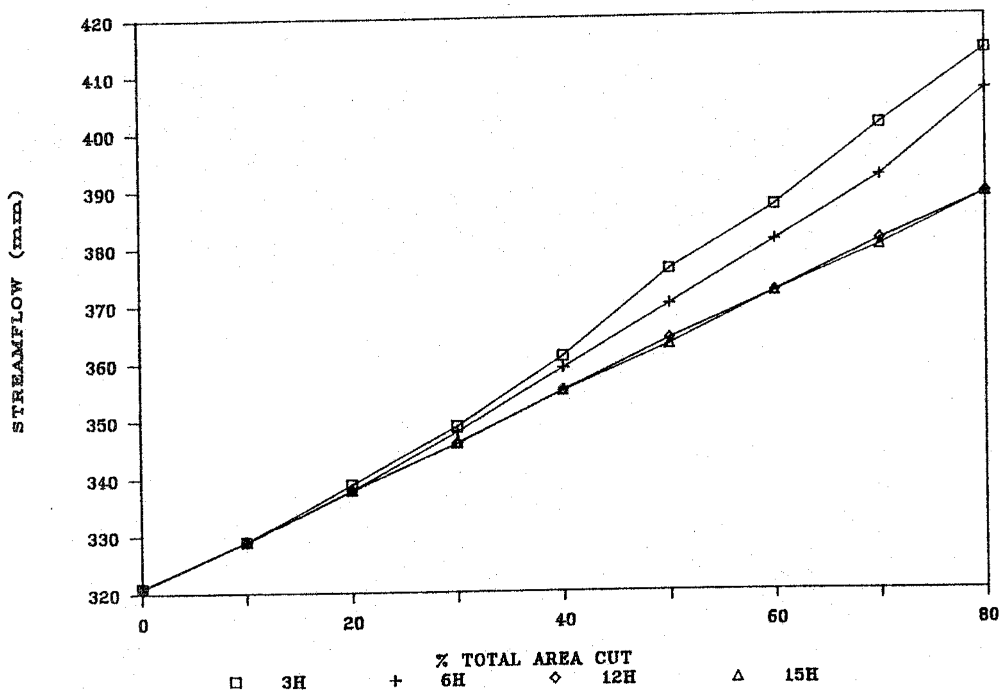

Figure 4. Streamflow as related to opening size and wind speeds of 0m/sec.

DISCUSSION

Precipitation

Precipitation data are rarely available for a specific watershed. Often precipitation data are recorded near the stream gauging site, and thus a conservative estimate of basin precipitation given orographic influences. Changes in seasonal precipitation data and the resultant change in streamflow were not calculated, since both WRENSS models should be used for annual streamflow estimates only.

The best way to evaluate the effects of a silvicultural treatment or other vegetation manipulation on water yield is to physically measure water yield. The next comparison is between predicted and actual water yield changes. Annual water yield estimates are affected by precipitation representativeness of the basin and watershed storage. From 1967 to 1971, Fool Creek at Fraser Experimental Forest in Colorado had an average annual water yield of 319mm, and an average annual water yield increase of 67mm over the uncut forest (Alexander and Watkins, 1977). Using precipitation data from a station near the mouth, WATBAL predicted an annual yield of 203mm and annual increase of 58mm. Precipitation data from a station located at mid-elevation in the watershed predicted an annual yield of 318mm and annual increase of 62mm (Swanson, 1987). One could argue that the predicted change in water yield is of most utility, even though water yield increase estimates are conservative for the snow dominated regions (Troendle, 1988, pers. com.). Certainly the annual water yield estimates are only as good as the basin precipitation estimates.

Forest Stand Characteristics

Evapotranspiration rates are vegetation species specific. Evapotranspiration calculations at Fraser Experimental Forest indicate a threefold difference in annual transpiration for stands of equal basal area, or 3.2:2.1:1.8:1 for Engelmann spruce, subalpine fir, lodgepole pine, and aspen respectively (Kaufmann, 1985). WATBAL in theory

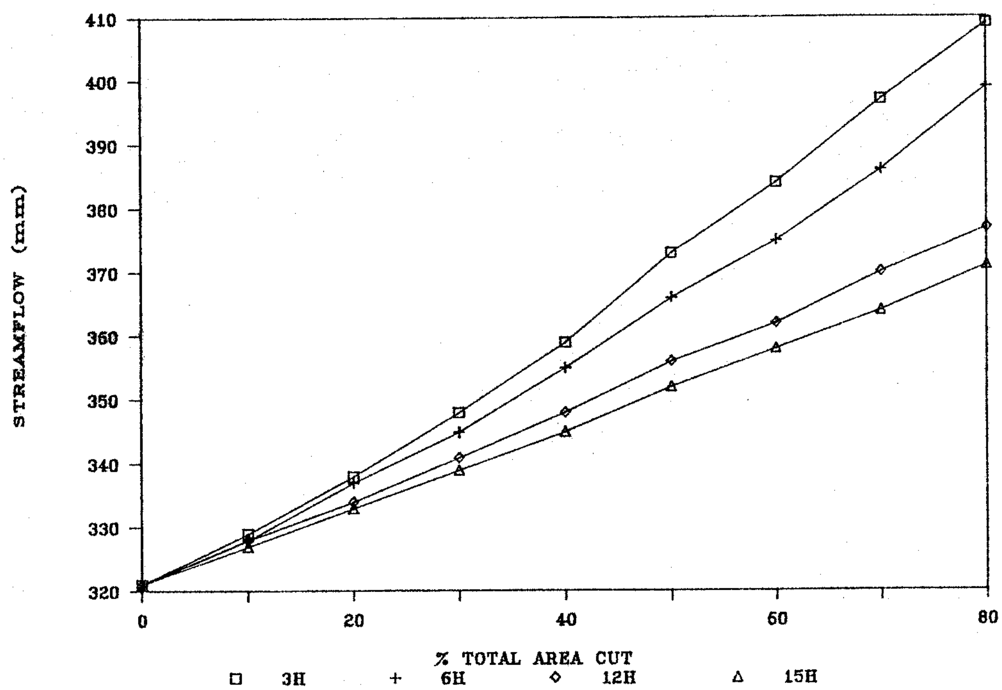

Figure 5. Streamflow as related to opening size and wind speeds of 1m/sec.

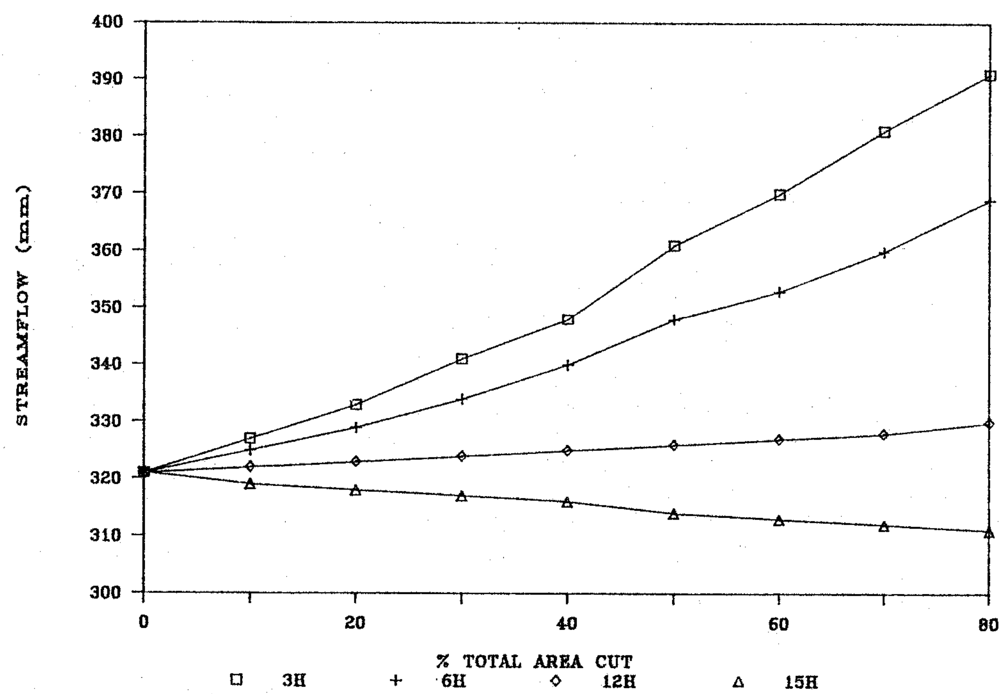

Figure 6. Streamflow as related to opening size and wind speeds of 5m/sec.

recognizes evapotranspiration rates as a species function, however the model is not sensitive to this input.

Evapotranspiration was maximized at a stand basal area of $20m^2$/ha. This suggests that the model recognizes evapotranspiration as being energy limited and species differences may not be evident given this premise. Evapotranspiration in the subalpine forest appears water limited in the summer and energy limited in the winter.

Forest Opening

Openings of 5-6H modify stand aerodynamics to maximize snowpack accumulation. larger openings may be subject to wind scour while smaller openings have less ability to modify stand aerodynamics and snowpack accumulation.

Partial cutting and thinning in the subalpine forest has suggested that winter interception losses are reduced, resulting in increased soil water available for streamflow (Troendle, 1986). Further, redistribution of intercepted snow from the surrounding forest to the opening is insignificant (Wheeler, 1987). The mechanics of snowpack accumulation in different forest environments needs to be better defined.

Watershed Storage

Streamflow is the result of precipitation minus evapotranspiration plus or minus the change in watershed storage. Watersheds with shallow soils in the snow dominated region are considered to have minimum soil moisture storage changes. The calculated annual water yield is water available for streamflow and may not truly represent streamflow generation. If watershed storage is significant, several years of record should be used to obtain an average annual water yield.

CONCLUSIONS

The WATBAL model will accurately predict annual water yield increase due to silvicultural treatment or other vegetation manipulation. The change in annual water yield is approximated by the difference in cut and uncut forest conditions. The annual yield increases as predicted by WATBAL are conservative for the snow dominated region but within physical measurement error and considered accurate. The annual water yield is only accurate given watershed representative precipitation data. WATBAL predictions of annual water yield were not sensitive to vegetation species, stand characteristics, or aspect.

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