MANAGING LODGEPOLE PINE ECOSYSTEMS AS WATERSHEDS

Robert H. Swanson

ABSTRACT

The lodgepole pine forest type occupies portions of the Colorado, Columbia, Fraser, Missouri and Saskatchewan river headwaters in Canada and the United States. The on-site needs of fish for habitat and clean water, as well as the needs of downstream water users must be considered during any forestry operations in these watersheds.

Clear-cutting of lodgepole pine forests alters streamflow by localizing snow accumulation and reducing evapotranspiration. The physical features of a managed forest that most affect its water-yielding characteristics are treed-cleared edge and clear-cut size. A 50:50 pattern of treed and clear-cut patches no larger than 2-6 tree heights across in any direction should produce maximum water yield from immature, stagnant, or mature lodgepole pine forests anywhere within its range.

The Northern Forest Research Centre has produced an interactive FORTRAN program for the hydrology portion of the USFS WRENSS procedure. This simple-to-use procedure estimates the annual water yield change that will occur under a wide variety of silvicultural practices.

INTRODUCTION

Watershed management is management for a specific water-oriented goal. It is not necessarily the same as good forest management, fisheries management or any other type of "multiple use" management. One would hope that the implementation of a watershed management system could be described as good forest management. However, one should not be surprised if management for a water-oriented goal results in different rotations and cutting patterns than management for any other forest product.

Lodgepole pine of commercial quality occurs from central California to the Yukon Territory. Annual precipitation over this region ranges from less than 300 mm in such widely separated places as Bend, Oregon, and Whitehorse, Yukon Territory, through a moderate 500 mm in Colorado to over 2000 mm in Oregon, Washington and southeastern Alaska. Throughout most of this range, snowfall is heavy (40 to 60% of annual precipitation), supplying the major portion of soil moisture for early season growth of lodgepole pine (Satterlund 1975; Lotan and Perry 1983). However, the species also thrives on the Eastern Slopes of the Canadian Rockies, where snowmelt from a light winter snowpack is augmented by moderate to heavy rain in May and June (Hillman *et al.,* 1978).

The wide areal distribution of lodgepole pine forests makes it difficult to generalize on the need for watershed management in these forests. Lodgepole pine occupies substantial portions of the headwaters of rivers such as the Athabasca, Colorado, Columbia, Fraser, Missouri and Saskatchewan. The latter five have large population centers downstream. The importance of watershed management in these headwaters varies directly in proportion to the needs of those water users.

There is no question of the value of water in the Colorado River. The water receives heavy domestic and agricultural use and is apportioned among a wide variety of users. The small headwaters catchments of the Columbia and Fraser rivers contain tributary streams vitally important to the Pacific Salmon fisheries. On the other hand, the waters of the Athabasca River are mainly used for local fishing and boat traffic. Watershed management would necessarily receive higher priority in the headwaters of the Colorado, Columbia and Fraser rivers than in those of the Athabasca.

The seasonal distribution of normal streamflow, and the time at which water is needed downstream are also of importance in establishing a need for watershed management in the headwaters. For example, many of the streams in Canada flow north and are normally ice filled downstream at the time of snowmelt in their more southern headwaters. If a combination of high natural flow and ice is already creating a problem for downstream users, a forest cutting scheme that would augment flow during the snowmelt period by a major amount would generally not be desirable. Most clear-cutting practices do augment flow during the snowmelt period (Swanson and Hillman 1977).

Watershed management is a form of forest management designed to produce desired streamflow characteristics. One objective of any watershed management program must be to enhance the usability of water for water users. Within such an objective, the following three broad categories of management may occur:

1. Management to protect the watershed and tree cover to retain the beneficial forest influences on soil and channel stability, water quality and flow timing. According to Hoover (1975), the "least risky" way to achieve this would be to leave the forest untouched.
2. Management to protect the stream and its inhabitants from undesirable changes in water quality or stream habitat. This type of management requires that the manager pay particular attention to erosion-sedimentation processes.
3. Management to deliberately increase usable water supply. This type of management must necessarily be a response to users' requests.

Once a water yield objective has been defined, then the response of forest management can take one of the following five forms:

a. The water users' requests are considered unimportant. They must live with the timber management plan.
b. Timber production is the prime goal; however, wherever possible, and if timber production costs are not unduly affected, then water users' needs will be considered and accommodated within the management plan.
c. Timber and water are equally important coproducts. The management plan will reflect concerns for both with neither occupying an overriding position to the detriment of the other.
d. Water is the primary product. Timber harvesting and measures to minimize fibre production costs will be accommodated as long as they do not unduly affect water production goals.
e. Water is the only management product. Timber harvesting, if done at all, must be done solely for the purpose of enhancing or maintaining prescribed water benefits.

In my opinion, most present-day forest management on watersheds falls under the first or second type of response. Except for "leaving the forest untouched," each of the above three categories of management represents some management activity on the part of the land manager to satisfy the needs of timber and water users. Such activity must be based on the energy exchange characteristics of sites and vegetation (Satterlund 1972) if it is to achieve predictable results.

There are two ultimate users of the product of watershed management: those on-site and those at some remote point downstream. There is a legitimate concern that increased water in the stream channel, seemingly desirable for downstream users, may be accompanied by increased sediment to the detriment of instream residents. Unfortunately, the concerns that people express for water values are often concerns about aesthetics or a desire to prevent logging in their particular playground. The watershed manager must carefully define who his customers are, if their problems relate to water, and if and/or how these concerns can be met by some form of forest manipulation.

In many instances, downstream water users have already provided the impetus for water management. Up to this point in time, the emphasis by water managers has been to increase supply by diversion and storage. This emphasis is being questioned, and one of the growing fields of research is that of water demand management, i.e. the manipulation of demand to coincide with the supply (Tate and Reynolds 1983). Further, the president of Resources for the Future (Castle 1983) has stated that in the 1980s, water conservation and efficiency of use will receive greater emphasis than interbasin water transfers. In my opinion, managing a forested watershed in a manner that will optimize its usable water yield is a valid way to conserve and improve water supply within a river basin.

Watershed management is not just management to increase water yield; it is also management to protect the land surface from erosion, the stream from degradation and the quality of the water. Most studies have shown that surface erosion and the sedimentation of streams can be effectively controlled through the application of proper engineering techniques, close supervision of activities during the road construction and skidding phases of timber extraction operations and prompt reclamation of disturbed sites (Hoover 1975; Anderson *et al.*, 1976). Other studies have shown that some sediment in streams originates from mass wasting and slumping into the stream channel. These occurrences represent a soil stability problem that is often associated with excessive on-site soil water. In areas where precipitation greatly exceeds evapotranspiration, the role of trees in removing excess soil water is probably minimal (Swanston 1974). In the more xeric conditions that are normal for lodgepole pine forests, water use by trees may play an important part in maintaining soil mass stability (Swanston and Dryness 1973; Swanson 1981). The mitigation of excess water problems requires that the forest manager schedule timber removal in a manner to maintain high rates of water use by the remaining trees. This is the opposite effect to that desired to increase water yield, but the same hydrologic principles are involved in establishing the forest management practice to achieve either objective.

In this paper, my main emphasis is on the management of lodgepole pine forests to increase water yield rather than protection from erosion. I will discuss the general potential of this forest type for water yield improvement and briefly outline the manageable components of the water balance and the type of forest harvest that should produce maximum water yield. Then I will discuss several forest management strategies to affect significant water yield improvement, and the relationship of water augmentation forestry practices to those for other products. Lastly, I will outline the research needs that I see in the field of watershed management.

POTENTIAL OF LODGEPOLE PINE TYPE FOR WATER YIELD AUGMENTATION

Clear-cut harvesting of lodgepole pine forests is the established silvicultural practice throughout most of Canada and the United States. According to Anderson *et al.* (1976), the potential increase in water yield from patch clear-cutting Rocky Mountain lodgepole pine forests is 76 mm, which is equal to what could be achieved in the seemingly-wetter Engelmann spruce-fir type in the same region.

The changes in annual water yield that will result from clear-cutting are relatively predictable because the physical characteristics of forests that most influence the hydrologic processes involved are crown density and residual stand arrangement. The abrupt edge between treed and clear-cut areas provides a physical barrier that influences snow distribution and shelters accumulated snow and low vegetation from wind and solar radiation. These effects are not dependent upon the absolute height of the surrounding trees. It is as possible to create a stand arrangement favorable for water yield increase in the short, overdense and small diameter stands that are common to fire-origin lodgepole pine as in those with higher economic value.

Excellent compendia or comprehensive reviews of the relationship of forests and forest harvesting practices to hydrological processes are available (Sopper and Lull 1967; Anderson *et al.*, 1976; Baumgartner 1981; AWRA 1983). I will cover only the salient points below.

Precipitation

Precipitation is the general term for all atmospheric moisture contacting the earth's surface. The two most important forms of precipitation are rain and snow. The total quantity of precipitation received by a watershed is governed by external conditions such as overlying air masses, adjacent water bodies and nearby mountains. Once precipitation is occurring, interaction with surface vegetation affects how it will be distributed among various loss, storage and transport component processes of the hydrologic cycle.

Interception and Areal Distribution

Part of the rain or snow that falls on a forested watershed adheres to the canopy. Some of this evaporates and some finds its way to the soil. That which evaporates is lost from streamflow. The amount actually lost is quite variable, depending upon the form and intensity of the precipitation, weather conditions during precipitation and the form and density of the forest canopy. Troendle and Leaf (1980) give a value of evaporation from intercepted precipitation of 15-20% of precipitation for coniferous forests.

Differential distribution of snow on the ground is an obvious occurrence in forests. More snow accumulates in clearings within the forest than under the canopy. The source of this snow was once thought to be purely reduced interception. More recent studies have shown that much of the increased accumulation is from the canopy of the surrounding trees (Hoover and Leaf 1967). A stand edge is a barrier to the smooth flow of wind. The turbulence near this edge induces snow accumulation along the border within the cleared area at the expense of accumulation within or under the canopy. This is a rather long-lived effect that continues to occur until the regrowth in the clearing is at least 3/4 the height of the surrounding stand (Gary 1979). The turbulence near stand edges may affect the ultimate surface deposition of rain as well as snow; however, I know of no studies that have demonstrated this.

The source of increased snow on the ground would simply be an academic argument if it did not influence how we must manage a forest to utilize this phenomenon to augment water yield. If the source were purely reduced interception loss after clear-cutting, then any size of clearing would accumulate more snow to achieve the desired effect. If the source is redistribution as well, then clearings must be interspersed within sufficient surrounding canopy to provide the snow that will ultimately accumulate in them.

Both processes operate in lodgepole pine forests. The type of snow that occurs throughout most of the lodgepole pine range is dry and cold. It is readily transported short distances by modest wind speeds. Maximum accumulation is found in clearings with maximum dimensions of 2-6 tree heights (Hoover and Leaf 1967; Golding and Swanson 1978; Troendle and Leaf 1981).

Once snow has been deposited on the ground surface, it may be physically displaced by wind action. During transport it is subject to loss by evaporation. While in place the snowpack is subject to ablation by either evaporation or melt. Both evaporation and melt are energy driven processes that are dependent upon temperature and turbulent (wind) transfer processes. The wind regime at a clear-cut surface is highly dependent upon the presence of surrounding trees. In Alberta, I have found that the wind speeds at 2 m height in the center of clearings greater than 15-20 tree heights across are similar to those present above the canopy, i.e., the surrounding forest has little or no effect on the windiness of these larger clearings. In clearings smaller than 6-10 tree heights across, the surrounding trees have a major effect as wind speeds are generally 1/10 to 1/20 of those measured above the canopy (Swanson 1980). The effect of clear-cut size on surface wind speed is a major determinant of transport and of evaporative loss from accumulated snow (Tabler 1975; Troendle and Leaf 1981).

Evapotranspiration From Treed And Cleared Areas

Evapotranspiration is a term describing the combined processes of direct vaporization from any surface (evaporation) and that which occurs mostly from within the stomatal cavities of leaves (transpiration). The importance of evapotranspiration in the water economy of a forest depends upon the type and time distribution of precipitation. The magnitude of evapotranspiration and the relative proportion of direct evaporation to transpiration are the hydrological loss components that forest cutting affects the most.

Transpiration is the major loss component from fully treed land. Baumgartner (1967) gives average values for the relative amounts of water lost by evapotranspiration as 10% direct evaporation, 30% as evaporation from from intercepted water and 60% as transpiration. Annual transpiration from a mixed lodgepole pine-Engelmann spruce stand in Colorado was estimated at 292 mm, 46% of the 639 mm precipitation occurring that year (Swanson 1975).

When a forest is rearranged from fully treed to partially clear-cut, the amount of water formerly transpired by the trees removed would seemingly be available as additional soil water or streamflow; however, water yield increases have usually been less than the estimated transpiration reduction. At least some of the water lost as transpiration prior to harvest is lost as either direct evaporation from the soil and vegetative surfaces of the clear-cut and/or transpiration by pre-existing understory or newly established vegetation in the clear-cut. Because energy availability and turbulent transfer processes determine the conditions for any vapor loss, one should expect the proximity of surrounding canopy (e.g. clear-cut size) to affect evapotranspiration from the newly-exposed surfaces of a clear-cut in much the same manner that snow ablation is affected. (For an example of the shelter effect on evaporation, see McNaughton 1983).

Cutting Pattern For Maximum Water Yield

The possibility of scaling clear-cut size as a multiple of surrounding tree height allows us to generalize a forest arrangement that should produce near-maximum water yield in mature as well as overstocked, stagnated lodgepole pine stands. This arrangement would be one in which 40-60% of the area was occupied by uniformly dispersed, clear-cut patches no greater than 2-6 tree heights in any dimension. Clear-cut patches of this size would accumulate and retain the snow redistributed from the surrounding canopy, and the surface of the clearing, whether snow or vegetation, would be protected from the full evaporative force of the above-canopy winds. This forest arrangement, although likely to produce maximum water yield, would not necessarily produce the most usable water because of the differing requirements of instream and downstream water users.

MANAGEMENT STRATEGIES FOR WATER YIELD AUGMENTATION

Both water and timber can be harvested from the same area. I am assuming that the existing timber management models are adequate to predict future yields if given site and rotation information. I will confine my remarks to water yield.

It is impossible to provide a general strategy of forest manipulation that will produce the desired water yield result in every situation. The needs of water users, which must be coupled with the physical and biological possibilities of the forest in a manner appropriate to the local climate and topography, are more diverse than those of the forest industry. One effective tool for deriving a site-specific management plan is a physically and ecologically based hydrologic system model, which estimates the effects on streamflow of various levels of forest cutting in that particular climatic and topographic situation (Ponce and Meiman 1983). Watershed research has provided a variety of such models to assist the manager in deriving site-specific management plans. I can't speak for forest hydrologists in the U.S. Forest Service, but those in the Canadian Forestry Service are more than willing to assist forest managers in the implementation and application of these.

The WRENSS Procedure For Estimating Annual Water Yields

A technique that is currently available and easy to use is the hydrology portion of the WRENSS (Water Resources Evaluation Non-point Sources in Silviculture) procedure devised by the U.S. Forest Service (Troendle and Leaf 1980). This procedure can be used to estimate the effect of a wide variety of forest-cutting practices on annual water yield. The information base from which it was developed includes most regions of the United States and Canada, and certainly those areas where lodgepole pine is of importance.

The data required to use this procedure are minimal. One needs only the seasonal precipitation value and an estimate of the basal area for the location in question in order to produce an estimate of both normal water yield (that which would occur in the absence of any cutting) and water yield under some pattern of clear-cutting. The Northern Forest Research Centre has used this technique extensively in Alberta and have found that it produces estimates of normal water yield within 10% of that measured. The estimates for treated water yield are consistent with those observed in experimental situations.

The water yields that would result from complete clear-cutting to almost any mixture of partial cutting can be estimated with WRENSS. The most reliable results appear to be obtained when clear-cut patches are less than 15 tree heights in any dimension. Results for larger clear-cuts may not be as reliable because the surrounding trees have less influence over the microclimate at their surface than in those clear-cuts less than 15 tree heights across. Estimates for these larger clear-cuts should be based on a knowledge of the altered microclimatic parameters, particularly wind speed. At present, there is no provision in the WRENSS procedure to input such local data, even if it were available. For most lodgepole pine stands, the trees are in the vicinity of 20 m tall; therefore the procedure functions best with clearings less than 9 ha in area. I consider the estimates for clear-cuts 15 tree heights across to be applicable to much larger ones if it is clearly understood that these are quite likely overestimates of water yield in windy locations.

The hydrology portion of WRENSS (Troendle and Leaf 1980) consists of 173 pages of text and graphs. Estimates are made using a "cookbook" approach through the creation of tables from graphical extractions. To say that potential users have been intimidated by the procedure would be an understatement! It took me several hours to work through it, and I am very familiar with both the research underlying the publication and the hydrologic processes involved.

At the Northern Forest Research Centre, we have digitized the graphs and prepared an interactive FORTRAN program that accomplishes the WRENSS estimates. The time required to examine a new situation is about 10 seconds using a mainframe computer or about 3 minutes on an IBM compatible personal computer. The program prompts for the necessary inputs and supplies defaults if the user desires. Table 1 is an example of the output.

Only the annual total water yields are valid estimates. The WRENSS procedure calculates intermediate values called "seasonal water yield." These calculated water yields may be positive, zero, or negative, depending upon the precipitation and evapotranspiration occurring during that season. The breakdown of WRENSS output into seasons is purely for the estimation of evapotranspiration loss from seasonal precipitation. The seasonal water yield values must be summed algebraically to determine an annual water yield total.

Time of Water Yield

I have mentioned several instances where the time at which a water yield increase might occur would be important to resident or downstream users. Another instance would be in evaluating the channel stability criteria used by Region 1 of the USFS. Average monthly flows are used in the channel stability criteria. However, Harr (1981) points out that the size and duration of instantaneous flow rates, rather than mean monthly or annual rates, are the principal channel-shaping events.

The input data used in the WRENSS procedure is seasonal precipitation and this technique cannot be used to directly estimate peak streamflow for any time period. The WRENSS handbook (Troendle and Leaf 1980) is somewhat misleading in this respect as it contains a section on estimating the portion of annual yield that would occur during a 7-day period. The technique that the authors used to obtain these 7-day values in snow dominated regions was simply one of apportioning the annual flow among 52 consecutive 7-day periods in the same proportion as a local hydrograph or the one that was used to generate the procedural example (Fool Creek on the Fraser Experimental Forest in Colorado for WRENSS hydrologic region 4). Unless one has prior knowledge of the effect of cutting on flow timing in his situation, he has no basis on which to select a particular hydrograph for the 7-day apportionment. A similar procedure is used to estimate flow duration in rain dominated regions, and the same arguments apply to its use there too.

At the present time, one must use a hydrologic model with hourly or daily values of precipitation to simulate daily flows if he needs an estimate of instantaneous peak flows. This could be the same hydrologic model that Troendle and Leaf (1980) used to produce the WRENSS procedure. Several years of streamflow and climatic data are required for the calibration and operation of this model (Leaf and Brink 1975). There are very few situations in which these data would be available in the absence of a long-range plan to provide them.

Table 1.—WRENSS estimates of annual water yield changes resulting from patchcutting 50% of a watershed in 4 ha blocks.

```
HYDROLOGIC REGION #6
NAME OF BASIN: ALBERTA LODGEPOLE PINE
AREA OF BASIN (SQ.KM)= 1.00
% IN N, E+W AND SOUTH ASPECTS: 33, 33, 33%

******* INPUTS FOR ASPECT: NORTH
PRECIPITATION (CM): 11.4
PRECIPITATION (CM): 20.6
PRECIPITATION (CM): 18.5
TREE TYPE: LODGEPOLE
BASAL AREA OF STAND: 35 SQ M/HA
MAXIMAL BASAL AREA: 35 SQ M/HA
% OF ASPECT CUT: 50
AVERAGE AREA OF CUTS: 4 HA
BASAL AREA IN CUTS: 0 SQ M/HA
HEIGHT OF TREES: 20 M
WINDWARD LENGTH OF CUTS: 10 tree heights

******* INPUTS FOR ASPECT: EAST+WEST
INPUTS IDENTICAL TO THOSE OF PREVIOUS ASPECT
******* INPUTS FOR ASPECT: SOUTH
INPUTS IDENTICAL TO THOSE OF PREVIOUS ASPECT

SEASON: OCT01-FEB28:
               NORTH          EAST+WEST         SOUTH
          FOR       OPEN   FOR       OPEN   FOR       OPEN
PRECIP    9.4       13.4   9.4       13.4   9.4       13.4
ET        3.3        2.2   4.8        3.1   6.6        4.2
FLOW      6.1       11.2   4.6       10.2   2.8        9.1

SEASON: MAR01-JUN30:
               NORTH          EAST+WEST         SOUTH
          FOR       OPEN   FOR       OPEN   FOR       OPEN
PRECIP    17.1      24.1   17.1      24.1   17.1      24.1
ET         7.2       7.4   10.9      10.5   15.8      18.7
FLOW       9.8      16.7    6.1      13.6    1.2       5.4

SEASON: JUL01-SEP30
               NORTH          EAST+WEST         SOUTH
          FOR       OPEN   FOR       OPEN   FOR       OPEN
PRECIP    18.5      18.5   18.5      18.5   18.5      18.5
ET        19.3      13.6   19.3      13.6   19.3      12.2
FLOW      -0.8       4.9   -0.8       4.9   -0.8       6.3

YEARLY FLOW CM: 18.5 **** CU DAM: 184.5
```

Water Management Options

There has been a lot of talk about cutting forests to augment water yield, but little or no action taken to implement a management plan (Arizona Water Commission 1974; Ffolliott 1974; Hurst 1974; Northwest Hydraulics Consultants Ltd. 1977; Hibbert 1981). The Government of Alberta is currently investigating the possibility of conducting a pilot scale forest harvest of a watershed greater than 100 km^2 in area specifically to increase the annual yield by 15% or more. Perhaps they have the cart before the horse, but one of the questions that keeps cropping up in their discussions of this pilot project is "how will a management plan to augment water yield affect commitments of timber to the local forest industry?" This is a valid question.

In order to get some idea of the type of management plans that could be imposed in Alberta, I have used the WRENSS procedure to estimate the water yield that would occur if a 100 km^2 watershed was harvested in its entirety into an even number of clear-cut and treed patches ranging from 0.16 to 16 ha (Table 2). I then used these data to ascertain the annual water yield from the watershed upon complete implementation of each of the following three forest management options:
a) water considered as the only product,
b) water as an equal coproduct with timber and,
c) water as an unimportant by-product of normal timber harvesting operations.
I have also included the water yield results from the forest management scheme proposed by Leaf and Alexander (1975) for the Colorado-Wyoming area.

Table 2.—Estimated annual water yields from a 100 km^2 lodgepole pine watershed in the Alberta foothills, using the USFS WRENSS technique for snow dominated hydrologic region 6, with annual precipitation of 505 mm, tree height 20 m, basal area 35 m^2/ha, with precipitation seasonally distributed as in Table 1. The patchcuts have been considered as squares, n[tree heights (H)] on each side. Y indicates annual yield in mm, I indicates increase above untreated yield.

Patch Size		ASPECT							
area	height	North		East-West		South		All	
ha	**H**	**Y**	**I**	**Y**	**I**	**Y**	**I**	**Y**	**I**
uncut	0	197	0	143	0	75	0	138	0mm
.16	2	240	43	194	51	121	46	185	47
.64	4	241	44	194	51	123	48	186	48
1.44	6	241	44	195	52	125	50	187	49
4.00	10	240	43	193	50	120	45	184	46
9.00	15	226	29	179	36	106	31	170	32
20.00	20	220	23	174	31	102	27	165	27

Water The Only Management Product

Timber harvesting is used solely as a tool to create and maintain a desirable arrangement of trees and clear-cut patches to maximize annual water yield. The clear-cut patches would have maximum dimensions of 2-6 tree heights and be kept free of tree-type regeneration in order to maintain water yields at the highest level. Timber cutting would be conducted in the residual blocks on a selection or group selection basis in order to maintain the stability of the treed patches which provide the contributing canopy and edge turbulence necessary for maximum snow accumulation and protection of the clear-cut surfaces from wind action.

The water yield increase under this option would reach a maximum of 49 mm as soon as completely implemented. It would remain at this level in perpetuity.

Water As An Equal Coproduct With Timber

The size and arrangement of the clear-cut patches would be the same as in option 1; however, regeneration would be encouraged in the clear-cut blocks. Under a 100-year rotation, the residuals would be removed starting at year 50. This option would not disrupt the flow of timber products.

The water yield increase under this option would reach a maximum of 25 mm at year 50. Thereafter it would remain constant in perpetuity.

Water As A By-product

Cut blocks would be 9 ha and larger. Residuals cut 20 years after the first entry. This option would affect neither the economics nor flow of timber products.

The water yield increase under this option would reach a maximum of 16 mm at year 50, and remain at that level in perpetuity.

Leaf and Alexander Timber And Water Model

In this scheme, all of the old-growth timber would be harvested from the area in 120 years. At 30-year intervals, approximately one-third of the area would be harvested in a number of evenly distributed, 5-8 tree height (maximum dimension) openings arranged in such a manner at to complement the natural landscape. At appoximately 10-year intervals, the density of stocking on some of the previously cutover areas would be reduced to one-fourth of the natural old-growth cover density. The expectation for this scheme is a stand of 2500 stems/ha at age 30 years.

The water yield increase under this option reaches a peak at age 61-70 with cyclical fluctuations occurring at each entry interval (Table 3). The average annual increase over the 120-year rotation is 54 mm.

Advance Preparation For Watershed Management

It is my view that the purpose of management is to foresee events and to prepare plans to allow for them. If timely water is foreseen to be a future problem or if peak flows are thought to jeopardize channel stability, then it is up to the forest manager to start getting the necessary data to conduct a proper hydrologic evaluation of any cutting practices proposed for the area. All predictive techniques in hydrology are based on the availability of precipitation, streamflow, solar radiation, air temperature, air humidity, and wind speed data for the areas concerned.

Watershed researchers are continually deriving new or improved models, but the input data for these models has not changed significantly. The forest manager should not postpone or delay the acquisition of these data in anticipation of better models in the future.

Table 3.—Projected changes in annual water yield resulting from timber harvesting in lodgepole pine, Deadhorse Creek planning unit, Fraser Experimental Forest, Colorado (Leaf and Alexander 1975).

Interval	Water yield increase, by treatment			
years	I	II	III	IV
0-10	44 mm			
11-20	44			
21-30	33			
31-40		62 mm		
41-50		58		
51-60		39		
61-70			79 mm	
71-80			73	
81-90			54	
91-100				72 mm
101-110				50
111-120				35
Average increase over 120-years: 54 mm				

RELATIONSHIP OF WATER MANAGEMENT FORESTRY TO OTHER FOREST USERS

Recreation

The perception of what constitutes proper recreational land is as varied as the number of users. I am sure that any one who insists that the land must look "natural" would not be happy with any forest management scheme. However, an area managed solely for water, (option 1 above) could be made to look "park-like" by creating irregular shapes and sizes of clearings. If the residual forest were maintained through some form of selection silviculture, as suggested, then the access necessary to carry out silvicultural operations would benefit the recreational user as well.

Wildlife Habitat

Option 1 above would probably be close to optimum management for wildlife habitat (Reynolds 1972). The clearings could be revegetated with browse species rather than trees. The quantity of edge and cover would remain constant and close to the maximum that one could create with any type of clear-cutting.

The remaining two options discussed above would be of lesser benefit to wildlife. The desire to regenerate the clearings with trees would reduce the browse possibility; however the amount of edge and cover would be large and maintained at a relatively high level throughout a rotation.

Intensive Forestry

Under most of the options outlined above, soil moisture would be significantly increased due to the increased snow accumulation and reduced evapotranspiration demand. Dahms (1971) has shown that under some circumstances, increased soil moisture does result in increased volume growth. According to Mogren and Dolph (1972), all factors significantly correlated with site index are related to the availability of water to trees. One might thus presume that the site index of these smaller clearings, where snow accumulation is increased for 50 years or more, would be increased by one or more level.

Obviously the water management only option discussed earlier would interfere with forest production. In the residual treed patches, the soil moisture available to trees near the clear-cut edges would be greater because of the greater amount of soil water in the clearings. This soil moisture would be available to a large portion of the residual stand because of the vast amount of edge that this type of patch clear-cutting would create. The productivity of the residual stands might also be improved through a program of replacing them with genetically superior stock.

In the second option, the possibility of translating these differing site conditions into improved growth and shorter rotations would probably depend upon the type of tree used to regenerate the clear-cuts. The local logepole pine is a conservative species that is well-adapted to the cold climate and relative dry site conditions prevalent in the Rocky Mountain interior. There is a wide range of variability in the growth rate of natural reproduction. Rehfeldt *et al.* (1980) estimate that simple mass selection techniques would produce gains in height growth of 11-45%. Unless one were to carry out extensive and very selective thinning of natural reproduction, selected or genetically improved stock would probably be required to take advantage of the changed regeneration and growing conditions that would be created under a system of intensive water management forestry.

RESEARCH NEEDS

There really aren't any outstanding problems that would prevent immediate application of some form of forest management specifically designed to augment water supply. There is a need to provide better quantitative means of evaluating or predicting the influence of wind on snow ablation and evapotranspiration from the surface of clear-cuts larger than 6-10 tree heights across, which would allow more confidence in the use of the larger clear-cuts in areas where the economics of wood products precludes the extra roading and management costs associated with the smaller ones.

There is a need for a practice of watershed management to develop. Without such a practice, there is no feedback to research of questions relevant to the forest manager. Watershed management research is in danger of repeating old experiments simply to provide an education for the researcher. Presumably, pilot studies are a first step toward such a practice. It will be interesting to see if those proposed in Alberta and Arizona are ever implemented.

There is a need for continuing forest hydrology research and the developments of techniques to interface hydrologic findings with silviculture. For example, research has established that both warm and cold micro-climates can be created through patterned forest harvest (Anderson 1963; Golding and Swanson 1978). Anderson's wall-and-step forest can be created with clearcutting progressing in a south-to-north direction to cause either early snowmelt in a warm microclimate at the south-facing cleared-treed area interface, or cut in the reverse direction to delay snowmelt in the shaded and colder north-facing environment. The microclimate that these patterns create should be examined with respect to their influence on regeneration and growth.

Lastly, there is a need for a physically-based physiological method to interface forest hydrology research findings, with respect to microclimate and soil moisture alteration, and tree growth and yield models. The term "site" that is now used is too vague and includes too many climate, soil, and biological characteristics to be useful in a physical-physiological context. Such a method should enable the tailoring of microenvironments specific to the regeneration, growth, and survival requirements of selected or genetically improved trees.

LITERATURE CITED

Anderson, Henry W. 1963. Managing California's snow zone lands for water. USDA Forest Service Pacific Southwest Forest and Range Experiment Station Research paper PSW-6.

Anderson, Henry W., Marvin D. Hoover and Kenneth G. Reinhart. 1976. Forests and water: effects of forest management on floods, sedimentation and water supply. USDA Forest Service Pacific Southwest Forest and Range Experiment Station General Technical Report PSW-18. 115 p.

Arizona Water Commission. 1974. Proceedings, 18th Annual Arizona Watershed Symposium, September 25, 1974, Phoenix, Arizona.

AWRA. 1983. Watershed management. (A series of seven articles). American Water Resources Association, Water Resources Bulletin 9(3):351-419.

Baumgartner, A. 1967. Energetic bases for differential vaporization from forest and Sopper and H. W. Lull, editors. Forest Hydrology, Pergamon Press, N.Y.

Baumgartner, David M., Editor. 1981. Interior west watershed management. Proceedings Symposium April 8-10, 1980, Spokane, Washington. Cooperative Extension Service, Washington State University, Pullman, Washington. 288 p.

Castle, Emergy N. 1983. Water availability: the crisis of the eighties. Canadian Water Resources Journal 8(4):57-66.

Dahms, Walter G. 1971. Growth and soil moisture in thinned lodgepole pine. USDA Forest Service Pacific Northwest Forest and Range Experiment Station Reseach Paper PNW-127.

Ffolliott, P. F. 1974. Potential for water yield improvement by vegetation management in Arizona. p. 47-51 *In* Proceedings 18th Annual Arizona Watershed Symposium September 25, 1974. Arizona Water Commission, Phoenix, Arizona.

Gary, Howard L. 1979. Duration of snow accumulation increases after harvesting in lodgepole pine in Wyoming and Colorado. USDA Forest Service Rocky Mountain Forest and Range Experiment Station Research Note RM-366. 7 p.

Golding, Douglas L. and Robert H. Swanson. 1978. Snow accumulation and melt in small forest openings in Alberta. Canadian Journal of Forest Research 8:380-388.

Harr, R. Dennis. 1981. Scheduling timber harvest to protect watershed values. p. 269-280 *In* Interior west watershed management: Proceedings of the symposium. [Spokane, Washington, Arpil 8-10, 1980]. Cooperative Extension, Washington State University, Pullman, Washington.

Hibbert, Alden R. 1981. Opportunities to increase water yield in the Southwest by vegetation management. p. 223-230 *In* Interior west watershed management: Proceedings of the symposium. [Spokane, Washington, April 8-10, 1980]. Cooperative Extension, Washington State University, Pullman, Washington.

Hillman, G. R., J. M. Powell and R. L. Rothwell. 1978. Hydrometeorology of the Hinton-Edson area Alberta, 1972-1975. Environment Canada, Canadian Forestry Service, Northern Forest Research Centre, Edmonton, Alberta. Information Report NOR-X-202. 171 p.

Hoover, Marvin D. 1975. Watershed management in lodgepole pine ecosystems. p. 569-580. *In* Management of lodgepole pine ecosystems, D. M. Baumgartner, Ed. Proceedings of the symposium. [Washington State University, Pullman, Washington, October 9-11, 1973].

Hoover, Marvin D. and Charles F. Leaf. 1967. Process and significance of interception in Colorado sub-alpine forest. p. 213-224 *In* W. E. Sopper and H. W. Lull, editors. Forest Hydrology, Pergamon Press, N.Y.

Hurst, W. D. 1974. The application of water yield research to the National Forests of the Southwest. p. 43-46 *In* Proceedings 18th Annual Arizona Watershed Symposium, September 25, 1974. Arizona Water Commission, Phoenix, Arizona.

Leaf, Charles F. and Robert R. Alexander. 1975. Simulating timber yields and hydrologic impacts resulting from timber harvest on subalpine watersheds. USDA Forest Service Rocky Mountain Forest and Range Experiment Station Research paper RM-133. 20 p.

Leaf, Charles F. and Glen E. Brink. 1975. Land use simulation model of the subalpine coniferous forest zone. USDA Forest Service Rocky Mountain Forest and Range Experiment Station Research paper RM-135. 23 p.

Lotan, James E. and David A. Perry. 1983. Ecology and regeneration of lodgepole pine. USDA Forest Service Agricultural Handbook No. 606, 51 p. Washington, D.C.

McNaughton, K. G. 1983. The direct effect of shelter on evaporation rates: theory and an experimental test. Agricultural Meteorology 29:125-136.

Mogren, E. W. and K. P. Dolph. 1972. Prediction of site index of lodgepole pine from selected environmental factors. Forest Science 18:314-316.

Northwest Hydraulics Ltd. 1977. Watershed management for increased yield. Report prepared for the Oldman River Study Management Committee, Alberta Environment, Edmonton, Alberta.

Ponce, Stanley L. and James R. Meiman. 1983. Water yield augmentation through forest and range management - issues for the future. Water Resources Bulletin 19(3):415-419.

Rehfeldt, G. E., R. C. Hamilton and S. P. Wells. 1980. Genetic gains from mass selection in lodgepole pine. USDA Forest Service Intermountain Forest and Range Experiment Station Research Note INT-283. (Pamphlet)

Reynolds, Hudson G. 1972. Wildlife habitat improvement in relation to watershed management in the Southwest. p. 10-17 *In* Proceedings 16th Annual Arizona Watershed Symposium, September 20, 1972. Arizona Water Commission, Phoenix, Arizona.

Satterlund, Donald R. 1972. Wildland watershed management. Ronald Press, New York. 370 p.

Satterlund, Donald R. 1975. Climatic factors and lodgepole pine. p. 297-309. *In* Management of lodgepole pine ecosystems, D. M. Baumgartner, Ed. Proceedings of the symposium. [Washington State University, Pullman, Washington, October 9-11, 1973].

Sopper, William E. and Howard W. Lull, Editors. 1967. Forest hydrology. Pergamon Press, N.Y. p. 813.

Swanson, R. H. 1975. Water use by mature lodgepole pine. p. 264-277. *In* Management of lodgepole pine ecosystems, D. M. Baumgartner, Ed. Proceedings of the symposium. [Washington State University, Pullman, Washington, October 9-11, 1973].

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

Swanson, R. H. 1981. Transpiration potential of contorta, radiata pine and Douglas fir for de-watering in mass wasting control. International Association of Hydrological Sciences Publ. No. 132. p. 558-575.

Swanson, R. H. and G. R. Hillman. 1977. Predicted increased water yield after clear-cutting verified in west-central Alberta. Environment Canada, Canadian Forestry Service, Northern Forest Research Centre, Edmonton, Alberta. Information Report NOR-X-198. 40 p.

Swanston, D. N. 1974. The forest ecosystem of southeast Alaska. 5. Soil mass movement. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station General Technical Report PNW-17.

Swanston, D. N. and C. T. Dryness. 1973. Stability of steep land. Journal of Forestry 71:264-269.

Tabler, Ronald D. 1975. Estimating the transport and evaporation of blowing snow. p. 85-104 *In* Snow management on the Great Plains: Proceedings Great Plains Agricultural Council, Bismark, North Dakota.

Tate, D. M. and P. J. Reynolds. 1983. Meeting the demand for industrial water: intermediate water transfers. Canadian Water Resources Journal 8(4):10-19.

Troendle, Charles A. and Charles F. Leaf. 1980. Hydrology. Chapter III, p. III-1 to III-173 *In* Water Resources Evaluation Non-point Silvicultural Sources (a procedural handbook). United States Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia. EPA-600/8-80-012. 861 p.

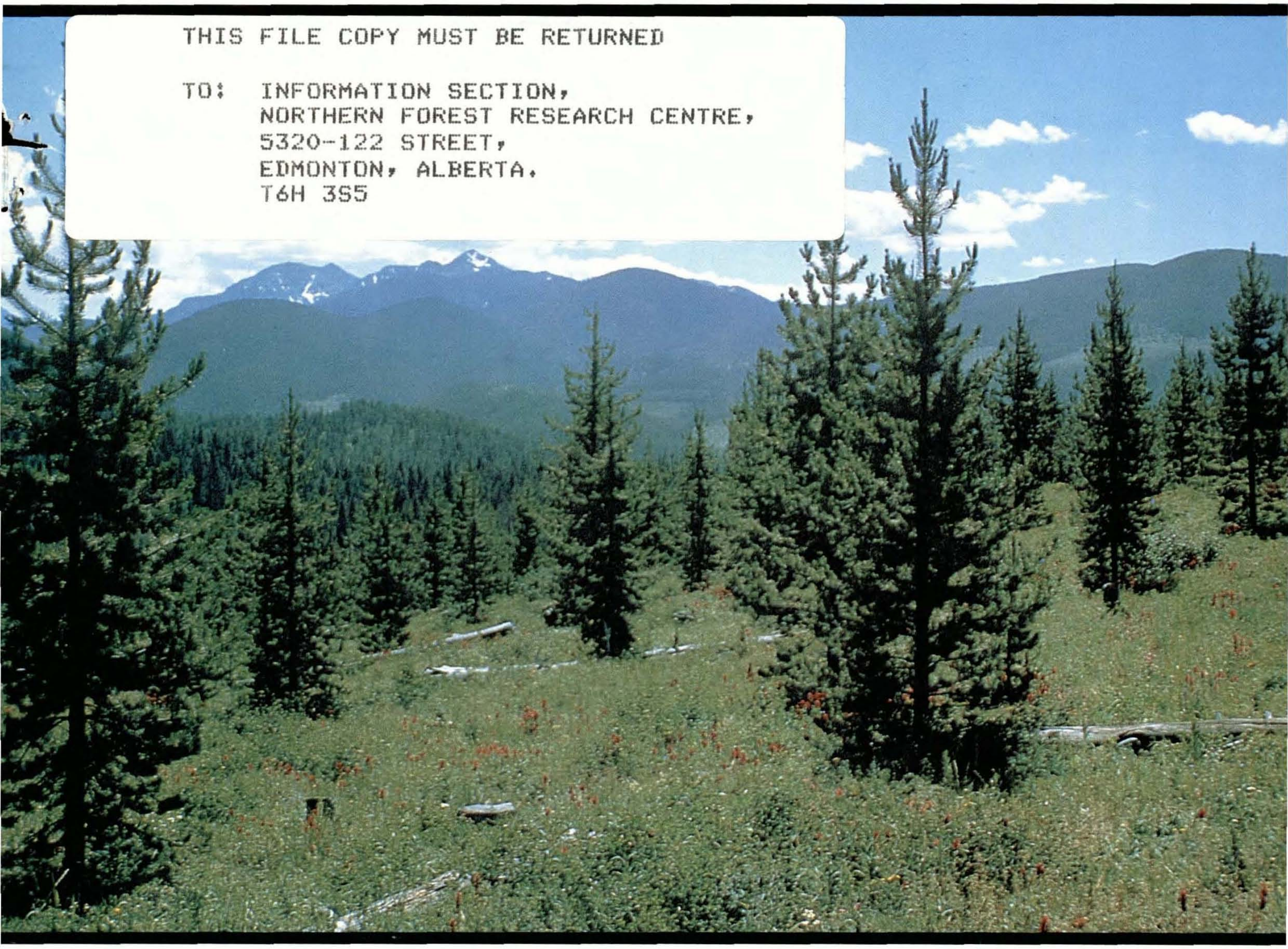
Troendle, Charles A. and Charles F. Leaf. 1981. Effects of timber harvest in the snow zone on volume and timing of water yield. p. 231-243 *In* Interior west watershed management: Proceedings of the symposium. [Spokane, Washington, April 8-10, 1980.] Cooperative Extension, Washington State University, Pullman, Washington.

AUTHOR

Robert H. Swanson, Project Leader, Forest Hydrology Research
Northern Forest Research Centre, Canadian Forestry Service
Edmonton, Alberta T6H 3S5

MANAGING LODGEPOLE PINE ECOSYSTEMS AS WATERSHEDS

Robert H. Swanson



Lodgepole Pine
the species and its management
SYMPOSIUM PROCEEDINGS

LODGEPOLE PINE
THE SPECIES AND ITS MANAGEMENT

SYMPOSIUM PROCEEDINGS

May 8-10, 1984 Spokane, Washington, USA
and repeated
May 14-16, 1984 Vancouver, British Columbia, Canada

Compiled and Edited By:

DAVID M. BAUMGARTNER, Washington State University, Pullman, Washington, USA

RICHARD G. KREBILL, Intermountain Forest and Range Experiment Station, Missoula, Montana, USA

JAMES T. ARNOTT, Pacific Forest Research Centre, Victoria, British Columbia, Canada

GORDON F. WEETMAN, University of British Columbia, Vancouver, British Columbia, Canada

Symposium Sponsors:

Alberta Forest Service

British Columbia Forest Service

Canadian Forest Service

Forest Research Council of British Columbia

Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture

University of British Columbia

Washington State University

PUBLISHED 1985

Additional copies may be purchased from:

Office of Conferences and Institutes
Cooperative Extension
202 Van Doren Hall
Washington State University
Pullman, WA 99164-5220