SNOW MANAGEMENT SEEMS UNLIKELY IN NORTHEASTERN FORESTS

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ABSTRACT

Research into the relations of snow, forests, and floods in the Northeast is summarized. Snowmelt rates average three times as fast in the open, and twice as fast under hardwoods, as under dense conifers. Snow accumulation is less under conifers than under hardwoods or in the open due to greater interception. Annual streamflow may therefore be increased somewhat by reducing the area in conifer forest. Concrete frost occurs generally in plowed fields, occasionally under conifers, and seldom in hardwoods, but its effect on floods has been overrated. Flood control is achieved by desynchronization, the melting of snow from different parts of a watershed at different times. Streamflow from northeastern watersheds is already highly desynchronized, as much by variations in slope, aspect, and elevation as by variation in cover type. Regional management of forested watersheds to reduce snowmelt floods is impossible because of ownership patterns and owners' desires; the possible effects of management are small anyway. Management of forests for protection from snowmelt floods need not be considered further in the Northeast.

In the past ten years desynchronization of snowmelt has become recognized as the key to flood reduction. On any watershed, a variety of vegetative cover types would reduce flood peaks from snowmelt because snow would melt earlier on some parts of the watershed and later on other parts. However, in the Northeast most watersheds are highly desynchronized already. Regional management to further increase desynchronization seems unlikely and would probably be ineffective.

Increasing water yield and prolonging streamflow into the dry summer months is a classic problem in snow hydrology. Altering certain cover types to reduce interception loss does seem to be a valid goal, but management to substantially delay snowmelt would probably be ineffective in the Northeast.

Snow management may be important on a strictly local scale. Reducing the area of frozen soil would help prevent erosion by surface runoff on agricultural land. Trees can be planted or cut to control blowing or drifting snow. Lof, Alperi, and Taft (1972) are studying such control on ski trails. The hydrologic effect of snowmobiles has also received recent attention (Hogan, 1972). However, we will not discuss these local problems further.

SNOW GEOGRAPHY IN THE NORTHEAST

The Northeast (the New England States, New York, and Pennsylvania) can be divided roughly into five geographical regions that vary in geology, vegetation, topography, and snowpack (table 1). Scattered throughout all these regions are river valleys filled with glaciofluvial or alluvial materials, which contain significant groundwater resources.

The average annual precipitation of 1,000 mm. (40 inches) in most of the Northeast is uniformly distributed throughout the year. In the persistent snowpack regions about one-fourth of this comes as snow.

Over the whole Northeast, snowmelt virtually always occurs when the soil is very wet, between field capacity and saturation. Soil water deficits of up to 12.5 cm. (5 inches) that were built up by transpiration in the summer are practically always satisfied by

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autumn rains. Thus refilling of soil water deficits is not a factor in snow management (Eschner et al., 1969).

Snowpacks ripen to densities of 0.30 to 0.35 before beginning to drain (Sartz and Trimble, 1956; Lull and Rushmore, 1960; Hart, 1963).

The snowmelt period in the regions of persistent snowpack (table 1) generally lasts from 2 to 4 weeks on any given site, beginning with peak water equivalents of about 25 cm. (10 inches). In regions of intermittent pack, snow cover of about 8 cm. (3 inches) water equivalent can melt completely in one to several days at any time during the winter.

Table 1.--Generalized snow geography regions in the northeastern United States

[Based partly on Lull, 1968]

Region	Geology	Groundwater recharge important	Vegetation	Topography	Snowpack
Northeastern New England	Till over impermeable	No	Spruce-fir	Flat-rolling	1 Dec.-30 Apr. persistent
Central New England & northeastern New York	Till over impermeable	No	Northern hardwoods	Hilly-mountain	15 Dec.-15 Apr. persistent
Central and western New York	Till over sedimentary	Locally	Agriculture, hardwood-pine	Flat-rolling	15 Dec.-15 Mar. persistent
Southern New England	Till over impermeable	Locally	Pine-hardwood	Rolling	1 Jan.-15 Mar. intermittent
Pennsylvania	Residual over sedimentary	Locally	Hardwoods, agriculture	Flat to hilly	1 Jan.-15 Mar. intermittent
Scattered valleys	Glacio-fluvial, alluvial	Yes	Agriculture	Flat	1 Jan.-15 Mar. intermittent

SNOWMELT FLOODS

Hoyt and Langbein (1955) described three major causes or types of floods in the Northeast: spring floods from rain and melting snow, summer and fall floods from tropical cyclones, and localized summer floods from convective storms. Spring floods can be subdivided into three categories: floods from snowmelt only, floods from snowmelt plus rain, and floods from rain only. All three kinds are important (Cuthbertson and Dickison, 1962; McMullen, 1967). Ice jams can intensify any flood.

The extreme flood of March 1936, which affected areas from Ohio to Maine, was caused by two heavy rainstorms in 6 days, high temperatures, deep snow, partly frozen ground, and ice-bound streams. From 25 to 75 mm. (10 to 30 inches) of water had to be disposed of. This flood has often been used to show how bad snowmelt floods can be. However Hoyt and Langbein (1955) felt that this type of flood was unlikely to occur again, so it makes a poor example.

Hoyt and Langbein (1955) also state that "Most major floods of record in the Northeast have been associated with melting snow, with runoff near 10 to 15 inches." However, analysis of their descriptions of 75 or so floods in the region from 1900 to 1952 indicated that only one-fourth of them involved snowmelt. Only a few of these can be considered major floods. Hopkins (1956) stated that the Northeast can expect a major flood about once every 5 years. If about half of the major floods involve snowmelt, then we can expect a major snowmelt flood only once every 10 years or so.

Snow requires energy for melting. In the Northeast, solar radiation is the primary energy source for snowmelt. But solar radiation alone cannot produce abnormally high melt rates or cause flooding. Snowmelt is most rapid in warm, humid, often cloudy periods, especially with high winds, when convection-condensation melt dominates (Federer, 1968; Hendrick et al., 1971). When such periods are accompanied by heavy rain, flooding can be expected.

MELT RATE AND VEGETATIVE COVER TYPE

Cursory examination of snowmelt indicates the possibility that vegetative management could affect flooding. Snow obviously lasts longer in the woods than in fields, longer in conifers than in hardwoods, and perhaps longest on shady edges. The length of time a snowpack takes to disappear is equal to the initial water equivalent of the snowpack divided by the average daily melt rate.

Average snowmelt rates for each degree of mean daily air temperature above freezing are 0.45-0.75 cm. $^{o}C^{-1}$ day^{-1} (0.10-0.16 inch $^{o}F^{-1}$ day^{-1}) in open areas, 0.27-0.45 (0.06-0.10) in hardwoods, and 0.14-0.27 (0.03-0.06) in conifers (Lull and Pierce, 1960; Hart, 1963; Satterlund and Eschner, 1964). Apparently a rough rule of thumb is that snow melts in the ratio of 3:2:1 in open, hardwoods, and conifers, respectively.

These ratios are supported by analysis of net radiation at the surface of melting snow. Federer and Leonard (1971) estimated values of 0.44 ly./min. in the open, 0.27 ly./min. in hardwoods, and 0.11 ly./min. in conifer cover during clear middays. Unfortunately there have not yet been any studies of comparative energy budgets in these three cover types.

Streamflow on gaged watersheds confirms the relation of cover type to melt rate. Growth of conifer plantations slowed melt on Shackham Brook in New York (Ayer, 1960; Schneider and Ayer, 1961; Satterlund and Eschner, 1964, 1965a; Ayer, 1968). Increasing amounts of conifer cover on the Sacandaga River in the Adirondacks from 1912 to 1950 also slowed melt rates; but a storm in 1950 that destroyed many conifers speeded melt again (Eschner and Satterlund, 1966). Conversion of Wappinger Creek in southern New York from farmland to hardwood brush has evidently delayed snowmelt (Black, 1968). On the other hand, clearing of a hardwood forested watershed in New Hampshire speeded the rate of snowmelt (Hornbeck and Pierce, 1969).

Differences in average melt rate for the whole snowmelt period are not necessarily the same as differences in melt rate during a snowmelt flood. The seasonal differences discussed above reflect differences in radiation melt, but flood events are dominated by convection-condensation melt. In these events, melt rates may rank in the same order--open, hardwoods, conifers--but the differences may be much smaller and are due to differences in turbulent transport rather than in radiation. Turbulent transport in forest canopies is very poorly understood (Federer and Leonard, 1971).

MELT RATE AND COVER DENSITY

Management can easily vary cover density within a forest type, as by thinning, or it can create small openings in the forest. Analysis of the effects of these changes is often difficult because the effects of accumulation and the effects of melt cannot easily be separated.

Horton (1945) measured melt rates of 0.40 cm. $^{o}C^{-1}$ day^{-1} (0.09 inch $^{o}F^{-1}$ day^{-1}) in hardwood forest and 0.27 cm. $^{o}C^{-1}$ day^{-1} (0.06 inch $^{o}F^{-1}$ day^{-1}) in denser hardwoods with some hemlock. In central New York, snow in brushy hardwoods melted faster than snow in mature hardwoods, and snow in thinned spruce melted faster than snow in dense spruce;

but thinning of red pine had little effect on snowmelt (Eschner and Satterlund, 1963). Lull and Rushmore (1960, 1961) related degree-day melt rates to canopy density measured by a spherical densiometer. They found that Melt rate (inch $^{o}F^{-1}$ day^{-1}) = 0.0762 - 0.0005 x canopy closure (%).

Weitzman and Bay (1959) compared melt rates for several cutting methods in black spruce stands. Over a period of 18 days the net melt was 0.5 cm. (0.2 inch) in uncut stands, 0.8 cm. (0.3 inch) under single tree selection, 4.3 cm. (1.7 inches) in shelterwood, 2.8 cm. (1.1 inches) in the middle of a cut strip, and 8.9 cm. (3.5 inches) in the middle of a cut patch. For a given cover type, melt rates increase as density decreases.

Melt near the sunny edges of conifer openings can be very rapid because of increased longwave radiation from the adjacent sun-warmed conifer crowns. On the other hand, snow in small openings in conifer stands, where sunlight does not penetrate to the snow surface, may melt even slower than under a complete conifer canopy, because the opening traps cold air at night. The same effects operate in hardwoods (Sartz and Trimble, 1956; Swanson and Stevenson, 1971) but to a lesser extent because the canopy is porous to both radiation and wind. Melt rates are thus relatively low in openings up to one or two tree heights in diameter, and increase as size of opening increases. Certainly points in openings that are more than three or four tree heights from the forest edge should behave like open areas with respect to melt.

SNOW ACCUMULATION AND FOREST COVER

Snow accumulation is the depth or--more significantly--the water equivalent of snow on the ground at any given place and time. Three processes cause large spatial variation in accumulation: blowing and drifting by wind, interception, and differences in antecedent melt.

Blowing snow has not yet reached the snowpack surface; it includes snow that was temporarily held by vegetation and then is removed by wind. Drifting snow is snow that is being relocated by wind after being on the ground as part of the snowpack.

Interception can be defined in three ways that often are not clearly differentiated. Temporary interception is snow that is retained for a limited time by a vegetative canopy. Sooner or later this snow must leave the canopy--as a solid, by gravity or by blowing; as a liquid after melting; or as vapor after evaporation or sublimation (Miller, 1966). Gross interception is snow-water that leaves the canopy either as vapor or as melt water that enters the soil. It excludes both snow that leaves the canopy as a solid and melt water that refreezes in the snowpack. Net interception includes only the loss as water vapor, which is a hydrologic loss from the soil-snow system.

Temporary interception is affected in part by canopy and branch geometry and load-bearing capacity (Maule, 1934; Lull and Rushmore, 1961). These same factors affect dumping, which is the gravitational removal of solid snow. As long as snow remains in the canopy, without dumping or blowing off, it is subject to the gross interception processes of melt and vaporization. The time that temporary interception exists varies greatly from storm to storm in the Northeast, depending on weather conditions.

In regions of permanent winter snowpack, differences in maximum water equivalent are sometimes ascribed to differences in gross interception. This is correct only if wind effects on deposition are negligible and if no antecedent melt or vaporization has occurred. Antecedent melt is all melt that has previously contributed to reducing the water equivalent of the snowpack below what it would have been had no melt occurred. Since any antecedent melt is greatest in the open and least in conifer stands, differences in gross interception are underestimated by measuring differences in peak accumulation.

The most comprehensive study of peak accumulation as a function of cover density was done by Lull and Rushmore (1960). Stands with densities between 0.2 and 0.7, as measured with a spherical densiometer, included hardwoods and thinned conifers. The peak accumulation in these stands was independent of density. Uncut conifer stands had densities greater than 0.7; water equivalents at peak accumulation were 70 to 80 percent of the values under hardwoods.

Weitzman and Bay (1959) found that thinning of aspen had no effect on snow accumulation. Eschner and Satterlund (1963) measured peak water equivalents of 12.5 cm (5 inches) in hardwoods and thinned red pine, 10 cm. (4 inches) in unthinned red pine, and 7.5 cm. (3 inches) in thinned and unthinned Norway spruce. Pierce, Lull, and Storey (1958) found peak snow depths to be 30 percent deeper in hardwoods than in conifers. Hart (1963) measured about 80 percent as much peak water equivalent in red and white pine stands as the 18 cm. (7 inches) found under hardwoods. All these data are consistent in showing reductions under well-stocked conifers to 60 to 80 percent of water equivalents under hardwoods and thinned conifers.

Maule (1934) was able to measure gross interception for individual storms because the snow disappeared between storms. Immediately after a snowfall, red pine, white pine, and hemlock stands had depths of 60 percent and Norway spruce had depths of 40 percent of those in hardwoods. These differences are larger than the differences found in studies of peak accumulation, perhaps due to the absence of antecedent melt. Trimble (1959) reviewed several studies and summarized gross interception for mature closed stands of various forest types as: aspen-birch, 7 percent; northern hardwoods, 10 percent; white pine and hemlock, 25 percent; red pine, 30 percent; and spruce-fir, 35 percent.

Differences in snow accumulation under hardwoods and in the open are variable. Although gross interception by hardwoods may be 10 percent, blowing and drifting can sometimes greatly reduce snow accumulation in the open. The snow is transferred to nearby forest, shelterbelts, hedgerows, or any other relatively protected location. Furthermore, antecedent melt tends to be greater in the open. So it is common to find snowpacks in the open with the same or lower water equivalent than in adjacent hardwood forest (Lull and Rushmore, 1960; Eschner and Satterlund, 1963; Hart, 1963). Snow courses in the Northeast are usually placed in hardwood stands to minimize wind effects while keeping interception low (Lalley, 1967).

Some attempts have been made to study the factors governing temporary, gross, and net interception. Miller (1966, 1967) showed qualitatively how complex the processes are, and how they interact. In the Rocky Mountains, gross interception is small because most temporary interception is removed by blowing (Hoover and Leaf, 1967). In the Northeast, this situation holds for most cold-front storms, in which snow is followed by cold weather and strong northwest winds. The greatest temporary and gross interception may occur in warm-front storms when the snow is initially wet.

Dissipation of gross interception, by either melt or evaporation, requires energy. Satterlund and Eschner (1965b) showed that many factors, all related to increased exposure, act to provide more energy to isolated masses of intercepted snow than to snow on the ground: increased turbulence in forests, the small cold content of intercepted snow, the drainage of cold air out of the canopy, longwave radiation and advection from parts of the canopy not covered with snow, and--most important--the low albedo of snow-covered conifer canopies (Leonard and Eschner, 1968). Eschner and Leonard (1968) weighed crowns of small pines and found evaporation losses could be 0.1 to 1.2 mm. in a day over the projected crown area. There seems little doubt that energy is available in the Northeast to produce gross interception of 30 percent of snowfall in conifer stands.

However, there is no evidence about the relative amounts of loss as melt water and loss as vapor; in other words, the ratio of net to gross interception. Hydrologically this difference is important. For example: 30 percent of 25 cm. (10 inches) of snowfall is 7.5 cm. (3 inches) of water. What part of this evaporates and what part becomes streamflow? This question remains unanswered.

Creation of openings in the forest has been a favorite way to attempt to influence snow accumulation. Openings of diameter or width equal to one tree height trap snow effectively in both hardwood and conifer stands (Baldwin, 1956; Sartz and Trimble, 1956, Weitzman and Bay, 1959; Miller, 1966). The trapping effect is due partly to lack of interception, but the effect of the opening on wind, and thus on blowing snow may be more significant. The processes have not yet been carefully quantified. When larger openings are created, wind shear may become strong at the ground, causing drifting loss, and the area behaves more like a completely open situation.

SOIL FROST

Hydrologists have long considered soil frost important in snowmelt runoff and snowmelt floods. However it now appears that the significance of the frost-flood relationship on forest lands has been overrated.

Soil frost occurs in several forms; but only concrete frost, which occurs in mineral soil, reduces infiltration sharply and thus has hydrologic significance (Post and Dreibelbis, 1942; Trimble et al., 1958; Stoeckeler and Weitzman, 1960). When there are several inches of concrete frost in the soil, infiltration is minimal; snowmelt and rain must leave the area as surface runoff, which has high erosive potential and may augment floods. The principal hydrologic question has been to determine when and where concrete frost occurs.

Organic matter on the soil surface, particularly litter, insulates the soil against freezing (MacKinney, 1929; Thorud and Anderson, 1969). Snow has a similar effect (Thorud and Anderson, 1969); 30 to 45 cm. (12 to 18 inches) of snow depth is sufficient to prevent penetration of frost (Atkinson and Bay, 1940; Hart, 1963; Hart and Lull, 1963). Vegetation hinders freezing by increasing longwave radiation to the surface and by reducing wind speed and thus sensible heat loss. However, vegetation also reduces incoming solar radiation. Effects of vegetation on soil freezing have not been quantified.

Concrete frost is the rule in plowed fields, common in pastures, fairly common in conifers, and infrequent in hardwood forests (Atkinson and Bay, 1940; Kienholz, 1940; Post and Dreibelbis, 1942; Bay, 1958; Pierce et al., 1958; Striffler, 1959; Stoeckeler and Weitzman, 1960; Lull and Rushmore, 1961; Hart et al., 1962; Megahan and Satterlund, 1962; Hart, 1963).

Concrete frost first enters the ground early in the winter before snow accumulates, so the influences of litter and vegetative cover are strong. Even after a few snowfalls, wind and melt in the open keep snow cover thin. Therefore frost is early and deep in bare fields, while pasture and stubble, which traps blowing snow, are better protected. Hardwood forests are well protected by organic layers and snow. Conifers have organic layer protection; but high interception, especially in spruce-fir, keeps snow thin; and frost occurs more readily than in hardwoods. Frost may occur directly under conifer crowns, but not around the edge of the crown where temporarily intercepted snow has been dumped (Lull and Rushmore, 1961).

Frost melts in spring both from the bottom up and from the top down (Kienholz, 1940; Belotelkin, 1941). Melting from below may remove some frost during the winter, while snow cover is still present (Lull and Rushmore, 1961; Megahan and Satterlund, 1962). Melting from the top cannot occur until after the snow cover has disappeared, so frost can disappear much sooner from open areas than from under conifers (Kienholz, 1940; Belotelkin, 1941; Sartz, 1957).

Concrete frost under hardwoods is never continuous enough, and under conifers is seldom continuous enough to impose overland flow on large areas. Areas without frost provide infiltration sinks. Only in the open, particularly on plowed fields, is overland flow significant. If the soil is compact enough, overland flow may occur in the absence of frost anyway. Erosion is a serious problem in such situations and management to reduce frost may help alleviate erosion.

In terms of snowmelt floods, however, the significance of presence or absence of frost is not obvious. Most of the water that infiltrates the soil in the nearly saturated conditions of spring floods becomes streamflow quite rapidly (Lull and Reinhart, 1972). In saturated soils, surface runoff occurs in the absence of frost (Dunne and Black, 1971). Furthermore, Satterlund and Eschner (1965) point out that the influence of peak flow from any small tributary is lost rapidly downstream, so that the total volume of streamflow from small areas is more important than the peak rate in affecting downstream floods. Management to reduce concrete frost may slightly reduce the amount and delay the timing of streamflow, but the importance of such management in reducing floods has not been and probably will not be demonstrated.

SNOW MANAGEMENT FOR INCREASING WATER YIELD

Annual streamflow averages about 50 mm. (20 inches) over most of the Northeast (Lull, 1968). If this were uniformly spread over the year, the Northeast would not normally have a water-supply problem. Shortages arise every year from uneven seasonal distribution, and occasionally, as in the early 1960's, from several years of below-normal precipitation. In the drought of the early 60's, large municipal reservoirs, particularly those of New York City, were so low that spring runoff did not refill them as it normally does.

In this situation, reducing net interception loss of snow would have been advantageous. Hardwood-covered watersheds might yield up to 75 mm. (3 inches) more snow-water than coniferous forests. Hardwoods also intercept less rain in their leafless spring and fall conditions. Removing vegetation completely over part of a watershed would reduce interception to zero as well as greatly reducing summer evapotranspiration. However, any devegetation may have adverse environmental and aesthetic effects. Conversion of forest to other vegetative covers, such as grass or shrubs, would reduce net interception loss; conversion of conifer forests to hardwoods would also reduce interception. On municipal watersheds such alterations appear to be feasible for obtaining more water from snow.

Low summer streamflow is a problem in the Northeast because transpiration utilizes practically all the summer precipitation even though rainfall averages about 90 mm. (3.5 inches) a month. In spring, on the other hand, streamflow is often excessive. Can anything be done to delay some of the snowmelt streamflow till summer? In the first place, one must recognize that peak water equivalents average only 25 cm. (10 inches) in the permanent snowpack regions, and that most of this melts in 2 to 4 weeks. Converting open areas to hardwoods and hardwoods to conifers does delay snowmelt and makes the snow disappear later. Even though conifers begin with less snow accumulation than hardwoods, the melt rate is sufficiently slower that snow is present later under conifers. The south edge of small openings may retain snow longest of any situation.

But the amount of delay that can be produced by management is only about 5 to 15 days (Weitzman and Bay, 1959; Lull and Rushmore, 1960; Hart, 1963). In the Northeast, upland areas have virtually no groundwater storage; the spring period of high flows is over in early June; and streamflow is governed thereafter by current precipitation and evapotranspiration. An effect caused by delay of snowmelt might last until early June, but water shortages come mainly in August and September. In the limited valley areas where groundwater is important, a delay effect might be more prolonged; but it is doubtful that any effect would remain by the beginning of August.

Concrete frost affects the ratio of overland flow to infiltration. In the Northeast, where there is no soil-water deficit during snowmelt, and in upland areas where groundwater storage is minimal, there is no difference between overland flow and subsurface flow in producing seasonal water yield. Regardless of whether frost is present or absent, practically all snowmelt becomes streamflow during spring.

SNOW MANAGEMENT FOR FLOOD REDUCTION

Over the past 20 years the philosophy of forest managers about preventing snowmelt floods has gone through three phases: "forests prevent floods"; "delay melt"; and "desynchronization."

The concept that "forests prevent floods" arose at the beginning of the century largely as an argument for forest conservation (Lull and Reinhart, 1972). It was supported by the concept of overland flow as the sole producer of floods. Forests had little concrete frost and high infiltration, no overland flow, and therefore by implication no floods (Storey, 1955).

Hoyt and Langbein (1955) opposed this concept, saying that "floods seem to roll out of forests as well as off farms." Their analysis of floods on the Connecticut River from 1840 to 1950 showed no trend in the size of floods, although huge areas of agricultural land on the watershed were abandoned during that period and reverted to forests.

Subsurface flow in forest soils is now known to be nearly as rapid as overland flow and to contribute just as large a flood volume when the soil is nearly saturated (Lull and Reinhart, 1972). In 1965, Satterlund and Eschner said that "reforested watersheds in this region appear to have a snowmelt flood potential as great or greater than that of agricultural lands."

In the second phase, hydrologists believed that the longer snowmelt could be delayed, the less would be the flood potential, because melt rate at any time would then be lower. This concept implied that hardwoods were better than open areas for flood reduction, and that conifers, with their high interception and slow rate of melt, were best (Weitzman and Bay, 1959; Lull and Pierce, 1960). However, Horton (1945) had already mentioned the possibility of an adverse effect of delaying melt: "the occurrence of a rain on ripe snow in the forest at a time when the snow-cover would have disappeared from an open area."

The problem became evident in analysis of the Shackham Brook results (Schneider and Ayer, 1961; Satterlund and Eschner, 1965a). Peak flows late in the snowmelt season were greater from the coniferous watershed of Shackham Brook than from the more open Albright Creek watershed (Satterlund and Eschner, 1964). Snow was still melting under the conifers long after it had disappeared from the open. The most rapid snowmelt of the year may be late in the season under hardwoods and thinned conifers when high temperature and radiation occur after snow in the open has gone (Eschner and Satterlund, 1963; Satterlund and Eschner, 1965a). Evidently if a large rain-snowmelt event occurs after open areas are bare, forest cover would be a liability rather than an asset.

"Desynchronization," a term that may have been used first by Schneider and Ayer (1961), appears now to be the key to snowmelt flood reduction. A variety of cover types scattered over a watershed will produce melt from the different covers at different times; this will optimally reduce flood potential throughout the snowmelt season. Eschner and Satterlund (1963) stated that a mixture of forest and open land may be the best land-use control of snowmelt floods in the northern Allegheny plateau. Increasing the proportion of conifers on predominantly hardwood areas is beneficial (Weitzman and Bay, 1959; Eschner and Satterlund, 1966). Any watershed that is dominated by a single cover type will be improved with respect to snowmelt floods by increasing the proportion of other cover types.

The only regional analysis of desynchronization has been done recently by Hendrick et al. (1971). Hendrick (1971) said, "the greater the diversity of forest cover, slope-aspect...and elevation over a watershed the greater the areal differentiation of melt rates and the greater the time staggering of melt over the spring season."

We have not previously discussed the effects of slope-aspect and elevation. Qualitatively the effects are obvious; but Hendrick's energy-budget approach quantifies them in the Northeast for the first time. Hendrick (1971) concluded that, "Here in the northeast a good beginning point for those who might improve management of our snow might be a full appreciation of how well behaved it already is."

Desynchronization also depends on weather. Periods of high radiation and temperature but low dewpoint and wind show the greatest effects of desynchronization. Periods of low radiation but high dewpoint and wind produce more rapid (up to 6 cm. or 2.5 inches each day) and more synchronized melts and are therefore much more conducive to producing floods. Fortunately most snowmelt in the Northeast is radiation melt.

The timing of periods of warm, humid air masses and heavy rain is also very important. Hendrick et al. (1971) compared a highly diverse watershed in the White Mountains with a highly uniform watershed in the Champlain Valley. The snowmelt period was short and early in the Champlain Valley, with a peak daily melt in 1969 of 3.0 cm. (1.2 inches). Melt in the mountains was greatly prolonged, the peak daily melt of 2.3 cm. (0.9 inches) coming late in the season. If a high melt and rainy weather situation occurs early in the snowmelt season, floods will develop from the open lowland areas. If, on the other hand, such weather occurs late in the melt season after snow is gone from the lowlands, floods can develop only from forested areas at higher elevation.

Two types of snowmelt floods can be distinguished; and the vegetation required to minimize the flood differs between them. In the first type, snow cover is still complete at the end of the flood and thus melt-water production depends only on melt rate, and not on the water equivalent of the snowpack. Flooding would then be reduced by reducing melt rate, so conifer covers would appear most favorable and open areas least. In the second type of flood event, snow cover disappears over part or all of the watershed during the event. The management objective for this type of flood is to minimize the initial water equivalent of snow. If sufficient antecedent melt has occurred, open areas would have a low water equivalent or even be snow-free, while conifers still retained a high water equivalent. In this type of flood, open areas would be most favorable, and conifers least. The management requirements for each type of flood are contradictory.

Managers must therefore prefer a variety of cover types in order to optimize desynchronization. Managers who are considering the effect of proposed alterations on snowmelt floods need not be concerned as long as the alteration is in the direction of greater desynchronization.

It is still not at all evident that management would significantly affect snowmelt floods. Hornbeck (1973) has demonstrated that clearing a hardwood watershed caused desynchronization of storm events involving snowmelt. However, when this same cleared watershed was considered as representing one-fourth of a forested basin, a significant change in snowmelt runoff due to forest clearing could not be detected (Hornbeck and Pierce, 1969). The small effects that were produced on the cleared area were quickly diluted by streamflow from the remaining unaltered area.

We have already mentioned that snowmelt floods are regional in nature and thus would require regional management. Yet the Northeast is an area predominantly of many, many small ownerships. Only in the northeastern part of New England (table 1) is forest land in large industrial holdings. In the other forested areas it has been difficult enough for foresters to interest landowners in timber production; interesting them in management to prevent snowmelt floods might well be impossible (Lull and Pierce, 1960). These owners are increasingly using their land for aesthetic and recreational purposes, which for most means leaving them without any alteration at all. Furthermore, extreme events overwhelm the effects of land use anyway; it is doubtful that optimum management could have significantly reduced the flood of 1936.

Many other aspects of managing watershed ecosystems in the Northeast are much more important than reduction of snowmelt floods. Snow management for flood reduction seems very unlikely in the Northeast.

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