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EFFECT OF SNOW FENCE HEIGHT ON WIND SPEED

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ABSTRACT. Accumulations of snow behind fences may increase the water yield in windswept areas. The efficiency of snow collection depends on the reduction in wind speed in the lee of the fence. Wind speeds have been measured to windward and to leeward of vertical slat fences from 6 to 16 ft. high. The down-wind measurements were made at distances of 2.5H, 5H and 10H from the fence where H is the height of the fence. Speed measurements at various levels were integrated up to the height of the fence and the percentage reduction in wind speed was calculated. Expressions are given for the velocity reduction factor at distances down-wind of fences having a bottom gap, and for the cross-sectional area of a fully developed drift.

RÉSUMÉ. Il se peut que des accumulations de neige s'amoncellant derrière une palissade augmentent le débit d'eau dans des régions exposées aux vents. L'efficacité du captage de la neige dépend de la réduction de la vitesse du vent du côté sous le vent de la barrière Des mesures de la vitesse du vent ont été prises de chaque côté (côté sous le vent et côté au vent) de barrières à planches verticales d'une hauteur allant de 6 à 16 pieds. Du côté sous le vent, les mesures furent prises à des distances de 2,5H, 5H et 10H de la barrière. 'H' représente la hauteur de la barrière. Les mesures de vitesse prises à des niveaux divers furent intégréés à la hauteur de la barrière et le pourcentage de réduction de la vitesse du vent fut calculé. Des formules sont données pour le facteur de réduction de la vélocité du vent à des distances du côté sous le vent de barrières munies d'une ouverture inférieure et pour la superficie de la coupe transversale d'une congère complètement formée.

INTRODUCTION

Snow fences have been widely used to protect highways, railways, and structures of various types for half a century or more. Only recently has attention been focused on their potential for inducing snow accumulation as a means of increasing water yield from windswept areas. Determining the best height of fence for a given site is a major problem yet to be solved, before snow fencing can be applied as a water management practice. Winter precipitation, fence performance, topographic interactions, and economic factors must all be considered.

The accumulation of snow behind a barrier reflects its effects on wind velocity, which directly determines the air's ability to transport snow. Knowledge of the effects of barriers on wind velocity should help expedite the intelligent use of snow fences as a water management technique. With models to predict fence performance, optimum design and siting offences could be determined for any given terrain situation or management objective.

Although many investigators have sought to determine the effects of shelterbelts, windbreaks, and fences on wind velocity, no information has been published which fully demonstrates the relation of barrier height to wind velocity reduction.

The length L of the velocity reduction zone (or resultant snowdrift) behind barriers has been more intensively studied than any other characteristic, due largely to the significance of this

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factor for snow protection purposes. It is a generally accepted simplification (Finney 1934, Nøkkentved 1940) that

$$L = K_1 H \tag{1}$$

where H is fence height and K_1 is an empirical coefficient that depends on the porosity of the barrier. K_1 ranges from 10 to 25, with a value of 16 typical for field tests (Mellor 1965) Finney also Nøkkentved provided evidence that K_1 may also vary slightly with approach velocity while Finney showed that the density of the drifting snow the for a given barrier porosity was important.

In wind tunnel tests, Finney showed that the maximum velocity reduction downwind of a fence depends on approach velocity and fence porosity as well as fence height. For a vertical slat fence of 50% porosity, he found this distance to be between 2H and 6H for windspeeds between 20 and 25 miles per hour.

Price (1961) showed that the maximum height of drifts behind slatted fences of about 50% permeability is about 1.15 times the fence height.

The cross-sectional area of the velocity reduction zone has been measured only as the resultant snowdrift at saturation. Finney proposed that the fully developed drift takes the shape of the velocity reduction zone behind the fence, but conclusive evidence is lacking. According to Pugh (1950) the fully developed drift typically does not fill that part of the eddy zone between the fence and the nose of the drift. Once a fence has "filled" according to the classical definition (with an ichthyoid-shaped drift of maximum height and length), this remaining part of the velocity reduction zone can also be filled with snow by winds blowing from the opposite direction. Although some investigators (Komarov 1954, Nøkkentved 1940) have proposed:

$$A = K_2 H^2 \tag{2}$$

where A is the cross-sectional area of the fully developed drift, the wide range of values reported for K_2 (6 to 18.4) make its validity questionable.

The objective of this study was to evaluate the influence of fence height on mean winds speed reduction, $\overline{R}_v$, defined (in percent)

$$(\overline{R}_v)_{KH} = \left[1 - \frac{\int_0^H v_d \, dh}{\int_0^H v_u \, dh} \right] 100 \tag{3}$$

where v_d and v_u are local wind speeds at height h downwind and upwind of the fence, respectively, and KH is the distance downwind of the fence in multiples of H.

2. FENCE ARRANGEMENT AND INSTRUMENTS

Five fence heights (6, 8, 10, 12, and 16 feet) were compared in pairs. The ten separate panels thus provided an incomplete-block design. Both portions of each panel were 10H feet in length. For example, the panel comparing the 16H and 8Hft heights was 160+80=240 feet long. Fences were constructed of the typical vertical-slat material with about a 50 per cent open area (porosity), and a 2 ft gap between the fence and the ground. The panels were well separated to prevent one panel from influencing another.

The area, on Pole Mountain in southeast Wyoming (at an elevation of about 7500 ft), has gently rolling topography. Shortgrass vegetation predominates on the upland areas; coniferous trees are restricted to perennial water courses and to some of the higher hills with conditions more favourable for forest growth. The snow fence panels are located on broad, open divides separating shallow drainage basins, with the terrain for most panels sloping about 4 per cent towards the east. The prevailing wind direction is from the west.

3. INSTRUMENTATION

Sensitive cup-type anemometers were placed at 1, 2, H/4, H/2, 3H/4 and H feet above the ground on two masts. One mast was located 10H feet upwind of the fence being studied, and the other was located at various distances downwind. Wind passage for 5-minute intervals was totalled for all anemometers simultaneously. Portable masts permitted adjustment of anemometer spacing, and were sufficiently mobile that terrain and snow drifts could be negotiated easily (Fig. 1). A millisecond timer controlled a bank of electromechanical totalizing counters for the readout system. Matching coefficients were determined for the anemometers over a flat surface by precessional comparison (interchanging anemometer positions on a horizontal board and comparing their performance over 5-minute periods at each location).

Figure 1. Portable mast 100 ft upwind of a 10 ft panel

Initial wind speed profile data were obtained in the late winter of 1966, at 2.5H, 5H, 7.5H, 12.5H, and 15H feet downwind of the fences. Only one fence of each height could be studied in the limited time available during the first winter. During these first measurements, profiles beyond 10H downwind were not often in the fence wake when wind direction varied during the run. Locations for subsequent measurements were thus limited to 2.5H, 5H, and 10H. In all cases, the upstream wind speed profile (upstream 10H) was determined simultaneously with each downstream profile. During November and December, 1966, wind speed profiles were determined for all 20 fences (10 panels) before snow began to accumulate. Days of measurement were restricted to mean wind speeds of about 12 to 40 mph (at H feet above the ground), with a maximum deviation from normal incidence to the fences of approximately ±45°. Although downstream wind speed measurements were carefully designed to be within the fence wake, this was difficult to determine in the field at distances of 10H and greater, particularly with light and variable wind. Some data were excluded from the analysis when the plotted profiles indicated questionable wind orientation.

4. METHOD OF ANALYSIS

The effect of each fence on ambient wind conditions was determined by mechanical integration of the wind speed profiles and calculation of the percent reduction of the wind speed by means of equation 3.

Reduction factors were calculated for each fence height at 2.5H, 5H, and 10H downstream (Table 1, Fig. 2). Only data from the 2.5H downstream measurements were used in the analysis

TABLE 1.

Wind speed reduction factors (per cent)

Total Fence Height H (feet)	Panel	Reduction Factor R_v		
		Downwind Distance		
		2.5H	5H	10H
6	1	27.0	*	*
	5	29.2	27.8	24.4
	6	32.3	26.1	19.0
	8	18.1	22.5	6.8
	Mean	26.6	25.5	16.7
8	2	—*	*	*
	4	31.2	28.9	26.8
	6	31.8	27.1	29.2
	9	39.2	30.2	29.2
	Mean	34.1	28.7	28.4
10	2	30.1	25.5	18.6
	3	27.6	—*	—*
	5	39.1	38.3	31.5
	7	38.1	27.4	28.4
	Mean	33.7	30.4	26.2
12	4	33.7	38.2	31.9
	7	39.0	33.0	31.4
	8	40.7	35.9	33.0
	10	37.8	39.4	12.0
	Mean	37.8	36.6	27.1
16	1	43.3	—*	—*
	3	41.1	40.3	12.8
	9	50.1	43.6	41.2
	10	48.1	41.8	34.0
	Mean	45.6	41.9	29.3

* Value not used. Measurement was not completely in the fence wake.

of variance for the block design. The data for the 5H and 10H measurements were not used because two questionable observations in the same block left insufficient information for analysis of variance. Because the 2.5H data for the 8 ft fence at one location was questionable, this value was estimated, which slightly decreased the accuracy of the analysis. Since ambient wind speed did not show an explicit effect on the wind speed reduction factor, it was ignored in the following analysis. The wind speed reductions are adjusted for fence position in a block as prescribed by the block design.

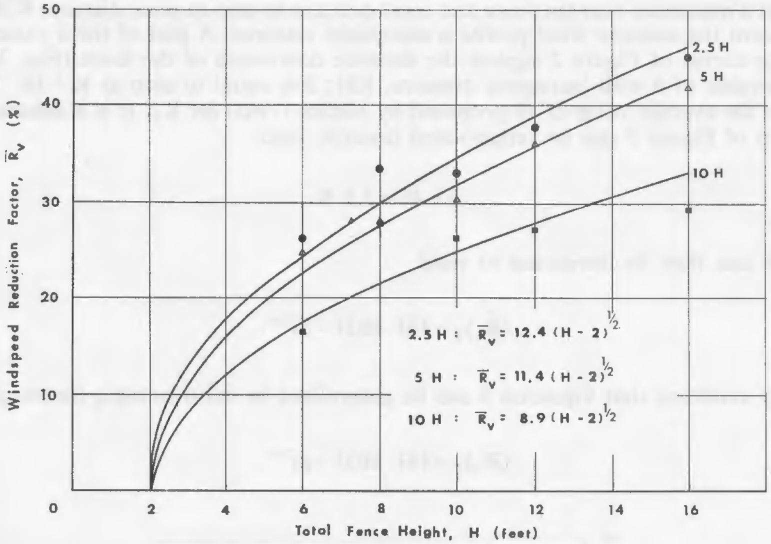

Figure 2. Relation of windspeed reduction to fence height, for distances 2.5H, 5H, and 10H downstream

5. *Effect of Height of Fence on Velocity Reduction Factor*

Data analysis indicated that height had a significant effect on the wind speed reductions. Comparisons between fence heights showed that the 16 ft fences produced a significantly greater percent wind speed reduction than the 6H, 8H, and 10 ft fences. The 12 ft fences also produced a significantly greater reduction than the 6 ft fences.

Although a linear model fits the data well over the range of heights studied, a curvilinear relationship is suggested by the requirement that $\overline{R}_v = 0$ when $H = 2$ feet (since there is a 2 ft gap between the ground and the bottom of the fence). A parabolic function of the general form

$$y^2 = 4ax \tag{4}$$

is convenient and fits the data closely. Thus, the general expression for the wind speed reduction factor at distance KH downwind of the fence becomes

$$(\overline{R}_v)_{KH} = 2a^{1/2}(H-2)^{1/2}. \tag{5}$$

A "total effective velocity reduction factor", $(\overline{R}_v)_T$, can be defined as

$$(\overline{R}_v)_T = \int_0^{K_1} R_v H \, dK. \tag{6}$$

As indicated by the least-squares fit of the curves in Figure 2, it was assumed that the functional form of the velocity reduction factor does not change with distance downwind. Thus, the parameter a is at a maximum near the fence and must decrease to zero at some distance K_1H (Eqn. 1), at which point the ambient wind profile is essentially restored. A plot of the $\hat{a}$ values for each of the three curves of Figure 2 against the distance downwind of the fence (Fig. 3) indicates a linear decrease of $\hat{a}$ with increasing distance, KH; $\hat{a}$ is equal to zero at $K \doteq 18$. This result agrees with the average value of 16 proposed by Mellor (1965) for K_1. If it is assumed that the relationship of Figure 3 can be extrapolated linearly, then

$$\hat{a} = 45 - 2.5 \ K. \tag{7}$$

Equation 6 can then be integrated to yield

$$(\overline{R}_v)_T = 161 \ H(H-2)^{1/2}. \tag{8}$$

Further, by assuming that Equation 5 can be generalized by substituting g for the gap height, then

$$(\overline{R}_v)_T = 161 \ H(H-g)^{1/2}. \tag{9}$$

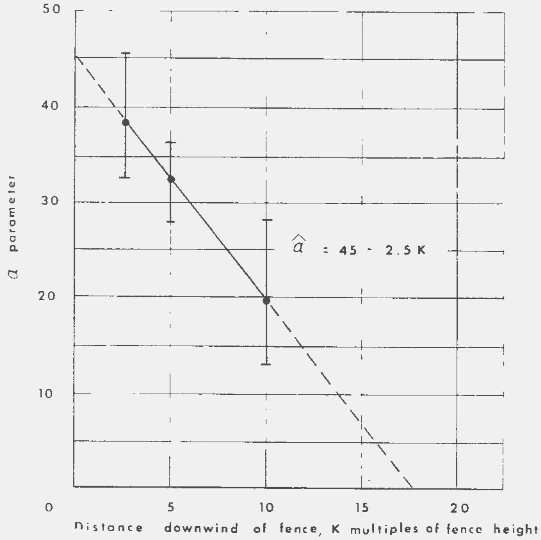

Figure 3. Values of $\hat{a}$ in the expression $\overline{R}_v = 2a^{1/2}(H-2)^{1/2}$ as related to distance downwind of the fence. Range bars indicate the 95% confidence interval

If the cross-sectional area (A) of the fully developed snowdrift that fills the velocity reduction zone is determined by the total velocity reduction factor, then

$$A = CH(H-g)^{1/2}. \qquad (10)$$

Equation 10 agrees well with snowdrift cross-sectional areas for fences 4 to 8 feet tall; it approximates the functional form (Eqn. 2) proposed by other investigators for these lower fence heights. For fences taller that 8 feet, values predicted by Equation 10 become increasingly smaller than those of Equation 2, up to 40% less for a 16 ft fence with the values of C we have determined from other studies.

If the assumptions leading to Equation 10 are valid, they could explain the report by Pugh that taller fences seem "reluctant" to saturate (that is, become filled with snow).

One measure of relative fence efficiency would be the percent reduction per foot of fence height (Fig. 4). The curves shown are for the equations of Figure 2 divided by H. This comparison indicates that efficiency, in this sense, decreases with increasing heights over the range studied.

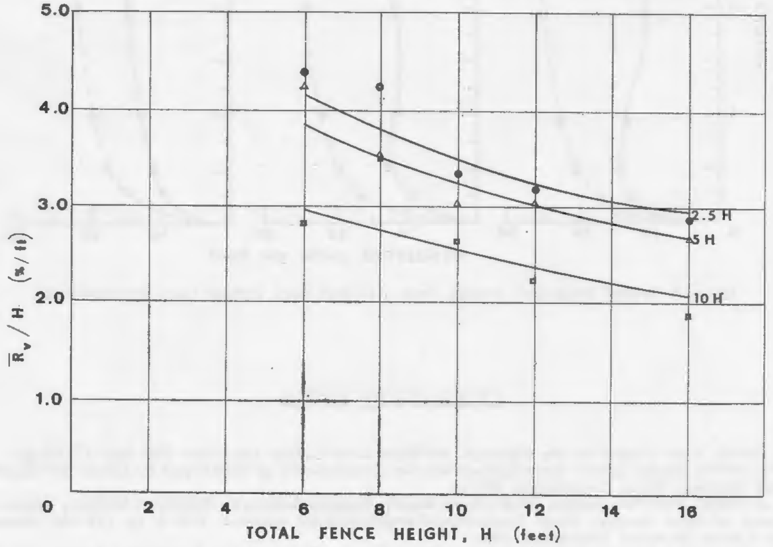

Figure 4. Relation of windspeed reduction per foot of fence height to fence height

6. *Windspeed Profile Characteristics*

Typical windspeed profiles for a 16 ft fence are shown in Figure 5. The higher speeds close to the ground caused by the 2 ft gap are evident at 2.5H downwind. At 5H this effect is considerably diminished, and at 10H the profile again approaches the logarithmic form of the ambient profile.

To simplify measurements as well as the analysis of data and presentation of results, several investigators have concentrated their measurements at certain reference elevations above the ground, scaled and expressed in terms of the ratio of instrument elevation to fence height.

Jensen (1954) in his definitive publication, demonstrated that for ungapped fences his "shelter effect" parameter was independent of measurement height up to the 0.4H level, both for wind tunnel experiments scaling surface roughness and also for field observations. He did not state, however, how his velocity reduction parameter varied with height behind fences with bottom gaps. Results from our study show a maximum wind speed reduction at about the 0.6H height at both the 2.5H and 5H locations downwind (Fig. 5). In nearly all cases, mean wind speed reduction was greater at 2.5H than at distances further downwind.

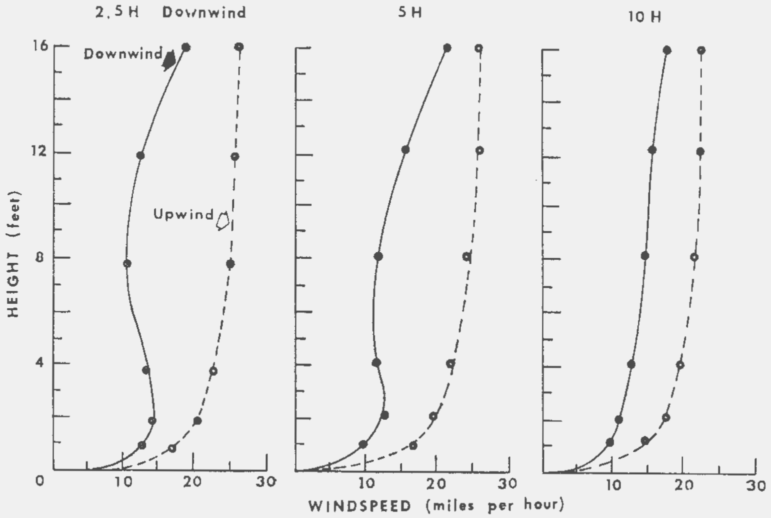

Figure 5. Typical windspeed profiles. from a 16-foot fence without snow accumulation

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