An Approach to the Design of Treatments To Prevent Snowdrifting on Highways

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Drifting snow causes hazardous driving conditions at many locations in Ontario. Drifting can be reduced by a variety of changes to the natural landscape, but selecting the best solution for each problem situation can be difficult, and the consequences of an inadequate treatment can be extremely costly. A standard design treatment and a computer modeling system have been developed to help reduce snowdrifting hazards on highways. The standard treatment involves a cross-sectional design and a vegetation scheme. Components of the treatment include a steep backslope, a wide storage ditch, a shallow sideslope, and a snow hedge that reduces the amount of snow reaching the highway. The snow storage requirement of the standard treatment is 31.5 m^3/m of hedge length. It was developed empirically from five seasons of snow accumulation measurements. The computer modeling system simulates the snowdrifting process over gridded areas of complex terrain, in time steps of 1 hr. The system can be used with real or design storm meteorological data to compare the effectiveness of landscape or geometric treatments proposed by the highway designer. Tests on highway sites in southern Ontario's snow belt have demonstrated the viability of the model, and it is now being incorporated into computer-aided systems for designing highways and planning roadside landscaping.

The Ministry of Transportation of Ontario (MTO) has a winter maintenance program to keep provincial highways clear of snow and ice that accumulate on the driving surface during winter (*1*). The program is carried out through active measures such as plowing and applying deicing chemicals and abrasives.

At certain highway locations, snow and ice problems are exacerbated by local topographic effects that cause fallen snow to drift onto the road. Drifting can result in several types of driving hazard. In the simple case, drifting snow sticks to the driving surface and accumulates in deep drifts. More plowing is required at the drifting sites than in the rest of the patrol area.

When a thin layer of snow accumulates, vehicle tire action causes the snow to melt and refreeze, forming a film of ice that requires additional applications of salt or sand. In other cases the drifting snow crosses the highway at windshield level or higher, obstructing drivers' visibility (a whiteout). Whiteouts create a particularly hazardous situation that can be remedied only by closing the road.

In addition to the safety hazard, localized snowdrifting reduces the efficiency of the maintenance program because extra equipment callouts are required to service very localized areas.

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MTO has developed a range of passive control measures to minimize the winter driving hazards caused by localized drifting snow. They are not used on all highways, only where localized drifting causes inconsistent driving conditions, safety hazards, or increased maintenance expense due to extra equipment callouts to service localized areas (*2*).

Passive measures of the winter maintenance program include the installation of temporary snow fences or permanent snow hedges, each of which reduces the quantity of drifting snow that reaches the road surface (*1*). Over a 25-year life cycle, passive treatments may cost up to 100 times less than active measures, depending on the relative occurrence of snow accumulation due to precipitation versus drifting (*2*).

Passive treatments are also incorporated in the geometric and landscape design of Ontario highways on a site-specific basis. In the past, the design of passive treatments required specialized expertise available only through the Research and Development Branch or private consultants. The design process was therefore expensive and time-consuming in comparison with the design process for the rest of the highway.

This paper describes an approach to the design of passive snowdrift treatments. It incorporates a standard design that is applicable in many highway situations, and a computer modeling system that can help highway designers with minimal expertise in snowdrifting to develop site-specific treatments where the standard treatment is not applicable.

MTO STANDARD TREATMENT

Description

A single treatment was developed at MTO that can be used to prevent localized snowdrifting in topographic situations common on Ontario highways: highways that are on shallow fill or in a shallow cut, have standard highway drainage ditches, and are exposed to snowdrifting from adjacent farm fields.

The standard treatment incorporates a right-of-way cross-sectional design and roadside vegetation scheme that prevent drifting snow from reaching the highway and provide off-road storage for plowed snow. The essential elements of the treatment are a snow hedge and a snow storage ditch. Other important features are a steep backslope, a wide storage ditch, a shallow inslope, and a vegetation scheme (Figure 1).

The purpose of the snow hedge is to interrupt low-level wind flow and cause snow carried by saltation and suspension to be deposited in a drift on the ground. Snowdrifts thus formed have a characteristic shape and length that are related to the height and porosity of the hedge and determine the

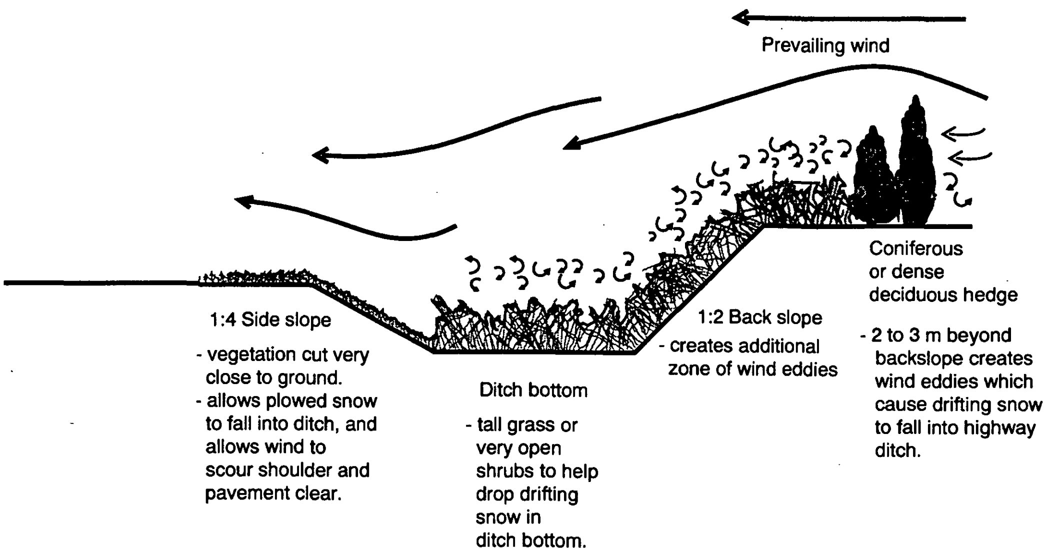

FIGURE 1 Right-of-way treatment for snow control.

required setback from the road (*2,3*). A setback of 15 times the mature height of the hedge is specified on level ground to ensure that the drift does not encroach on the highway (*1*), although shorter multiples are possible under certain conditions. The most effective hedges in Ontario are three-row spruce or two- to three-row cedar hedges. Very dense spacing and additional rows are required to achieve an adequate density where deciduous shrubs are used for snow protection.

The snow storage ditch, located between the hedge and the road, stores the drifting snow captured by the hedge as well as the fallen snow that is plowed from the road. The steep backslope causes a separation in the wind flow at the brow of the slope, to slow the wind further and ensure that any snow that remains entrained is deposited in the ditch. It reduces the setback requirement for the snow hedge as compared with the setback required on level ground.

The width of the ditch provides sufficient volume to accommodate the maximum winter accumulation of drifting plowed snow. Methods for calculating the required volume are described later. A minimum 5-m width is specified as a safety feature for errant vehicles.

The sideslope design has two purposes. A slope of 1:4 or shallower promotes a smooth wind flow from the ditch bottom over the road surface, so that any snow that has not been deposited in the ditch will be carried across the road. Physical model tests have shown that the brow of a slope steeper than 1:3 causes wind eddies at the shoulder rounding and results in the deposit of entrained snow on the windward edge of the pavement (*4*). The second purpose of the shallow sideslope is to obviate the guide rails on a fill section. Guide rails, which are required on a steep fill, interrupt the wind flow up the sideslope and frequently cause the deposit of snow on the pavement.

The vegetation scheme is coordinated with the geometric treatment. Tall grass or shrubs on the backslope and in the ditch bottom serve a similar function to the snow hedge and the steep slope in slowing the wind to ensure that all entrained snow is deposited before it reaches the inslope. Vegetation on the inslope should be cut as close to the ground as possible to minimize aerodynamic drag. Drag on the inslope would prevent acceleration of the wind up the slope and across the road.

Dimensions

Any treatment that acts on the principle of preventing drifting snow from reaching the highway must have the capacity to store the maximum winter accumulation of falling snow plowed from the road into the ditch and drifting snow deposited on the ground upwind of the road. Several methods are available for estimating the appropriate storage volumes.

Falling Snow

The falling snow storage is the annual maximum volume of snow that accumulates in the ditch. It is a function of snowfall onto the road and the ditch, minus melt and evaporation, adjusted to account for compaction by natural processes and plowing.

An estimate of the accumulated maximum snow depth for southern Ontario is provided by the Canada Department of Transport (*5*) (Figure 2). A suitable value for Ontario is 0.8 m (30 in.); this value accounts for losses due to drifting and compaction due to the metamorphosis of a natural snowpack, but it does not account for compaction by plowing. A factor of 0.5 can be used to account for plowing, and this results in a snow storage requirement for plowed snow in Ontario of about 0.4 m. This is approximately 20 percent of the mean annual snowfall for the same region (*6*). A typical, 4.5-m-wide highway lane and shoulder therefore requires $4.5 \times 0.4 = 1.8$ m^2 of storage for plowed snow times the length of highway affected.

Drifting Snow

The drifting snow storage requirement can be estimated either analytically or empirically. The empirical method was used

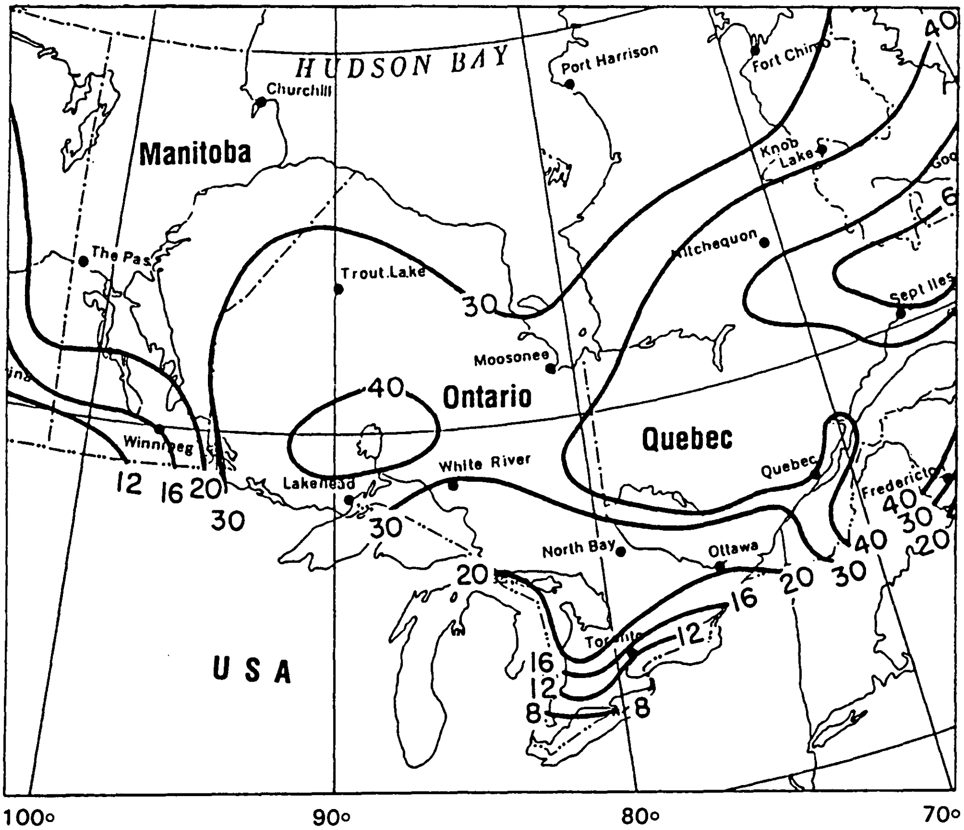

FIGURE 2 Median depth of maximum winter snow cover for 20 winters (1 in. = 2.54 cm) (5).

to develop a drifting snow storage volume for the MTO standard snowdrifting treatment.

Snow accumulation measurements are available from a variety of snow fence and snow hedge tests at six sites in the snow belt of southern Ontario over 5 years. All of the sites experienced severe localized snowdrifting. The maximum measured seasonal accumulation of drifting snow during these tests was 31.5 m^3/m of barrier length. This value occurred at a 4-m-tall snow hedge exhibiting an early stage of drift development throughout the season (*3*).

Numerical methods are also available for estimating the volume of drifting snow that should be accommodated by a drift treatment. Pomeroy developed physically based models of snow transport and sublimation (*7*) that were adapted by Tabler to estimate the flux of blowing snow at any site as a function of wind speed and height (*8*). The results are presented as a nomogram that estimates the total seasonal requirement for storage of drifting snow (in tonnes), as a function of wind fetch (*2*) (Figure 3). The nomogram makes assumptions about wind speed and frequency, relative humidity, snow density, and the proportion of total snowfall available for drifting. It also assumes a uniform ground surface.

The nomogram requires as input the relocated part of the annual snowfall in terms of mass. The relocated part of the annual snowfall is defined as the proportion of the annual snowfall that is available for drifting, should there be sufficient wind. This includes snow that is not trapped on the ground by gullies, vegetation, compaction, or crusting (*2*). The mean annual snowfall for the subject region is 2.84 m, as stated (*5*). It is converted to mass through multiplication by the snow water equivalent; Tabler recommends a water equivalent conversion of 0.1 g/cm^3, or 10 percent. The relocation factor is the proportion of the snow mass that is susceptible, over the winter, to drifting; Tabler recommends a snow relocation factor of 70 percent. Therefore, the mean annual depth of snow available for drifting is

$$2.84 \text{ m} \times 0.10 \times 0.70 = 0.2 \text{ m} \quad (1)$$

For a 1000-m wind fetch, the nomogram estimates a seasonal snow transport of 130 t/m of highway length. Assuming a snow density of 400 kg/m^3 (*9*), this converts to a snow volume of 325 m^3/m.

The model was adapted for use in southern Canada by an adjustment to the method of calculating the proportion of snowfall available for drifting (*10*). Using this adjustment and assumptions similar to those just mentioned, the model estimates a drifting snow volume between 112 and 175 m^3/m.

The calculated values differ from the storage requirement of 31.5 m^3 as derived from field measurements, by an order of magnitude, and suggest that additional investigation into this variable is needed. A value of about 30 m^3/m of highway affected is used in planning snowdrift treatments for provincial highways in Ontario.

The standard treatment is incorporated in sections of Highway 401, a four-lane freeway in southern Ontario. It provides protection from drifting snow under most conditions. In the

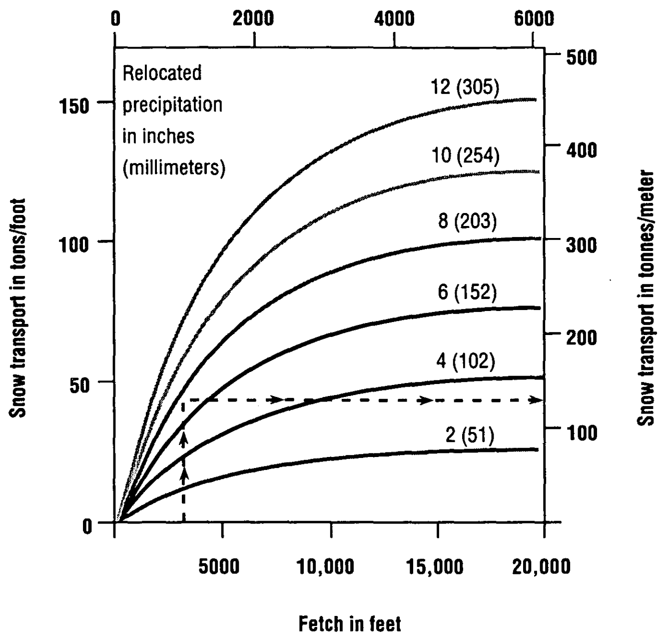

FIGURE 3 Variation of seasonal snow transport with fetch and relocated precipitation (*2*).

past 3 years the treatment has also been incorporated in plans for several two-lane rural highways in the same region that are being reconstructed. The treatment areas will be monitored after construction is completed to document changes in the severity of snowdrifting problems and assess the effectiveness of the standard treatment.

OTHER TREATMENTS

The standard treatment cannot be used in every situation. Among the conditions that preclude its use are these:

1. Sufficient right-of-way is not available or affordable;
2. Highway drainage requirements prevent excavation of a snow storage ditch;
3. Soil conditions are not compatible with snow hedge growth;
4. Snow problems are caused by drifting or by lack of storage but not both; and
5. Site problems are not addressed by the treatment.

In such cases, treatments must be individually designed. Two processes can be used to design individual treatments: analogues of previously used treatments, and computer or physical simulation of alternative treatments.

Previously Used Treatments

Treatments can be adapted that have been used in similar situations. Many of these were recently compiled in a catalogue of treatment designs for particular drifting problems (*10*). This catalogue provides a useful starting point, but most of the solutions are presented conceptually and it is up to the user to supply dimensions and other important details. Even if dimensions were provided, they would have to be adapted to fit specific field situations, and small changes to a treatment may reduce its effectiveness. Therefore, a risk of failure is inherent in analogues of previously used treatments.

On low-speed, low-volume roads or where the installed treatment may be changed with little expense, a moderate risk of failure may be acceptable. An example is a temporary snow fence that can be monitored by highway crews and adjusted or moved if necessary. On high-speed, high-volume roads, where a significant safety hazard could result from an unsuccessful treatment, or where budgetary considerations preclude adjustment, uncertainty must be reduced to a minimum before the treatment is installed. In such cases, an iterative process of design and preconstruction testing is recommended. This can be carried out by computer simulation.

SNOWDRIFT Model

A computer modeling system called SNOWDRIFT has been developed at MTO to assist highway designers who have no specialized expertise in snowdrifting to design landscape and highway cross-section treatments for drift prevention. The model simulates snow erosion and deposition due to drifting at any highway site and with any snowdrift prevention treatment specified by the user. It provides quantitative output that allows the user to compare objectively the effectiveness of different treatments.

The SNOWDRIFT model offers several advantages to the highway designer that are not offered by physical modeling, full-scale monitoring, or other numerical models.

1. Treatments can be changed or new sites input quickly and at no cost, using topographic maps;
2. Changes in snow properties that affect the propensity of the snow to drift can be accommodated;
3. Hypothetical or actual meteorological conditions—including snowfall, drifting, and melt periods—can be simulated without physical adjustments to the model;
4. Snow transport is simulated over complex terrain; and
5. Changes in surface roughness due to snow accumulation or erosion are automatically accommodated.

The modeling concept developed at the Centre d'Applications et de Recherches en Télédétection (CARTEL), University of Sherbrooke, recognizes that snowdrifting is affected by surface topography and roughness and by the changes in the terrain due to snow accumulation and melt through winter.

The initial condition of the terrain may be a snow-free surface of specified roughness, or a snow-covered surface. Snowfall is added according to data provided in hourly meteorological files. Erosion and deposition are then computed on an hourly basis, at grid locations within the modeling domain. This process results in a new topography grid and a new roughness grid that become the initial condition for the next hour (Figure 4).

The model assumes that the dominant transport mechanisms are creep and saltation within the height of influence of the surface roughness.

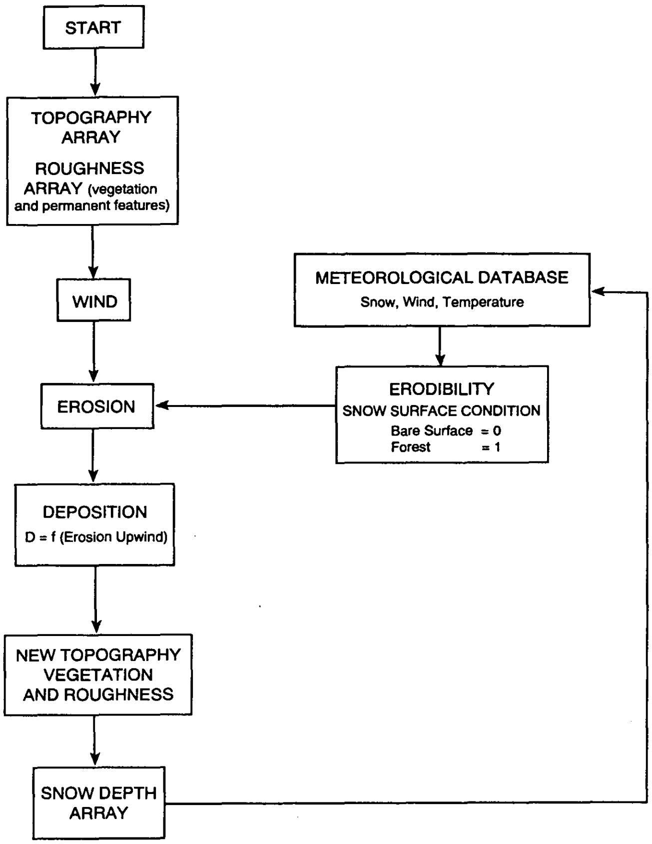

FIGURE 4 Simplified flow chart for SNOWDRIFT model.

Snow erosion is computed by

$$E(I,J) = (C_1\, W_s + C_2\, T_L + R_v/12)E_r \qquad (2)$$

where

C_1, C_2 = empirical coefficients,
W_s = function of wind speed and elevation of surrounding grid points,
T_L = parameter that accounts for local changes in topography,
R_v = local changes in surface roughness upwind of grid point, and
E_r = snow erodibility through empirical factors for snow age and air temperature.

Snow deposition is computed by

$$D(I,J) = A(I,J) - E(I,J) + S_f + S_p \qquad (3)$$

where

A = function of sum of depth of snow eroded from upwind three grid cells plus fallen snow and initial snow depth,
S_f = snowfall, and
S_p = initial depth of snow at that time step.

The model is designed to operate with input data that are readily available:

- Hourly wind speed and direction, air temperature, and precipitation type and amount (from the closest meteorological station);
- Topography within a domain of approximately 1 × 1 km, at horizontal resolution of 4 m or better (from highway surveys);
- Surface roughness expressed as vegetation or land use classes (Table 1); and
- Location of subresolution-calibrated snow control devices such as fences, hedges, and ditches (specified by the user).

Meteorological data are read from a spreadsheet file, topographic data are input from a digitizing tablet, and calibrated snow control devices are input from either a digitizing tablet or an interactive, on-screen system.

Results for each hourly period include contour maps of snow depth, profiles of snow depth at user-selected locations, and numerical summaries of snow accumulation on the pavement.

Figures 5 and 6 illustrate the on-screen display and results from a calibration run for a snowdrifting problem site on

TABLE 1 Surface Roughness Categories

Number Used on Map	Land-Use Categories	Snowdrift Model Roughness Values
1	Crop land	0.9
2	Tilled field	0.8
3	Natural grassland/pasture	1.0
4	Asphalt road	0.95
5	Gravel road	0.2
6	Deciduous trees	0.05
7	Coniferous trees	0.4
8	Deciduous shrubs	0.3
9	Coniferous shrubs	0.95
10	Buildings	1.0
11	Tower	1.0

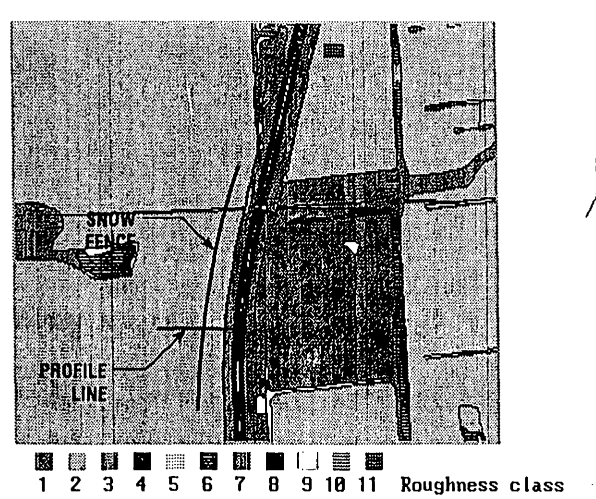

FIGURE 5 Land use/roughness map; Cochrane's Curve (Highway 400), 1.02- × 1.02-km plot.

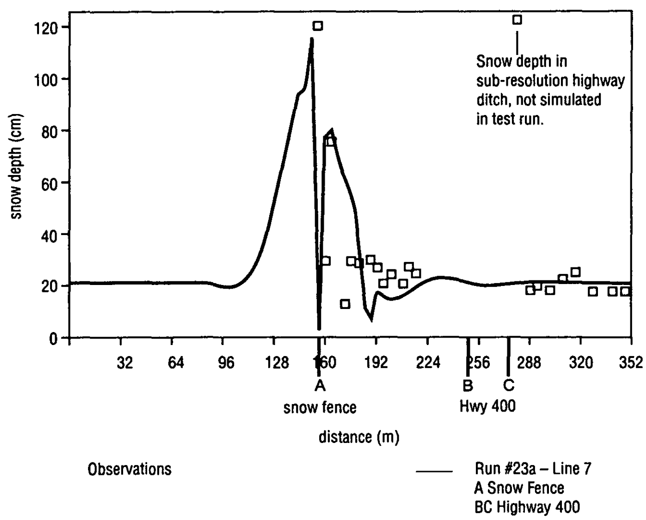

FIGURE 6 Observed and predicted snow depths along Profile Lane 7; based on Calibration Run 23.

Highway 400, a six-lane freeway north of Toronto. Figure 5 illustrates a terrain roughness classification map (see Table 1 for roughness classes), including the location of the highway and other roads, crop and forest areas, and cultural features. A user-input snow fence and a user-selected snow-depth profile line are also shown.

The model was run for 2 weeks beginning on December 1, 1989. This period began before the first lasting snowfall of the season and includes three snowfall events, three drifting events, and a short period of above-freezing temperatures. Winds were predominantly from the west.

Figure 6 compares measured and modeled snow depths at the end of the test period, at a profile line that crosses a snow fence and the highway. Major characteristics of drift shape, depth and location, and level snow depth are accurately represented by the model. An anomalous point at distance 280 m (snow depth 122 cm) is the snow depth measured in a highway ditch that was not simulated in the test run because it is below the grid resolution of the model. SNOWDRIFT is currently being calibrated for subresolution landforms such as highway ditches, as well as a variety of snow fences and hedges. Once the calibrations are complete, verifications will be performed using field measurements from locations and storms different from those used for calibration. Additional studies are planned to investigate the feasibility of reducing the model grid resolution from 4 to 1 m.

The model runs on a personal computer and is being incorporated into a mainframe, computer-aided drafting system that is used at MTO to design new highways, which will allow highway design staff with little or no expertise in snow science to develop and then test snowdrift treatments for any location in the province. SNOWDRIFT will provide three benefits to MTO: it will reduce the need for outside expertise or laboratory facilities, it will shorten the lead time required for designing and testing snowdrift treatments, and it will allow designers to identify areas that may be susceptible to snowdrifting on future highways before they are constructed.

The system also provides a useful tool for economic assessments of highway construction. It can be coupled with probabilistic weather data to establish the risk of different depths of snow accumulation, visibility reduction, or other driving hazards associated with treatments to prevent snowdrifts.

CONCLUSIONS

A rational approach has been developed for the design of passive treatments for prevention of snowdrifting problems on highways. It includes a specific design that is widely applicable at problem sites in Ontario, a source of conceptual designs for sites at which the problem is not addressed by the standard design, and a means of testing any treatment during the design process.

The standard treatment is designed to trap all of the winter's drifting snow and store it along with plowed snow in a ditch upwind of the highway. Dimensions of the standard treatment were developed from estimates of the required storage volumes. Field data suggest that treatments should accommodate 1.8 m^2 of drifting snow and 30 m^2 of drifting snow per meter length of treatment in southern Ontario.

Conceptual designs are provided in the literature for treatments in situations that are not addressed by the standard treatment. However, expertise is required to provide dimensions and other design details required for incorporation of the alternative treatments into a highway design.

A computer modeling system has been developed that can be used by personnel who do not have special proficiency in snowdrifting to test the effectiveness of any treatment designed to prevent drifts. This approach will reduce the risk inherent in the use of untested treatments.

The model can also be used to develop a risk-based approach to cost-benefit analysis of treatments for snowdrifting.

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