1.27 USING WYDOT SNOW DRIFT PROFILER

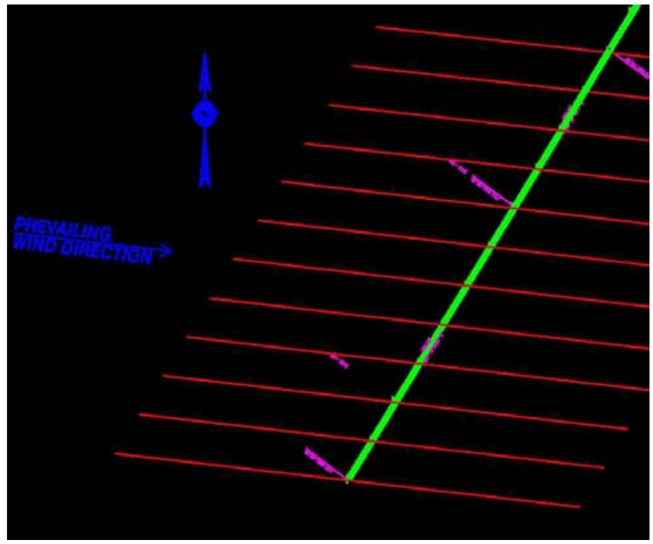
The WYDOT Snow Drift Profiler tool was developed using the *Algorithms for Generating Snow Fence Drift Profiles* developed by R. D. Tabler (2006), and additional equations from the *Controlling Blowing and Drifting Snow with Snow Fences and Road Design*, National Cooperative Highway Research Program Publication NCHRP Project 20-7(147) written by R. D. Tabler (2003).

The WYDOT Snow Drift Profiler tool is a Visual Basic Application (VBA) tool which requires both MicroStation and GEOPAK V8 (or later versions) to be installed and active on the local computer. This tool is not a part of GEOPAK, but utilizes GEOPAK's VBA language and commands to perform the snow drift profile modeling on existing and proposed cross sections.

> **WYDOT Snow Drift Profiler VBA Usage Agreement.** By using this design tool, the end user agrees to indemnifying, defending and holding harmless R. D. Tabler, the State of Wyoming, the Wyoming Department of Transportation, their officers, and employees from any and all claims, lawsuits, losses and liability arising out of or resulting from the use of this application including but not limited to any claims, lawsuits, losses and liability arising out of the end user's malpractice.
>
> Inquiries regarding the Geopak or MicroStation operation of this tool should be directed to the WYDOT Geopak Support Office.
>
> Inquires regarding the data input and drifting snow principles should be directed to the WYDOT Winter Research Services Office.

The Snow Drift Prediction tool will not design snow fence systems however, it can be used to optimize the setback and height for a single snow fence. The purpose of this tool is to develop snow drift profiles to visually indicate where snow drifts may occur in relation to existing terrain or design cross sections. This tool can develop drift profiles with existing ground cross sections only, or can develop drift profiles with a combination of existing ground cross sections, proposed design cross sections and a single snow fence. This tool will operate using English or Metric working units. The user has the option of selecting and placing four different heights of snow fence based on line styles selected through the Design and Computation (D & C) Manager. The snow fence porosity will default to 50% (Wyoming Standard) however, can be changed to 0%, 25%, 37.5% or 50%. The resulting drift profiles will be existing terrain drift profiles and a snow fence drift profile if a snow fence is being reviewed. The snow fence drift profile will be an equilibrium drift (drift generated by an unlimited amount of snow) in front of (downwind) and behind (upwind). By manually entering a local *snowfall water-equivalent* value, a *fetch distance* and a *relocation coefficient*, this tool will place an arrow on the equilibrium snow fence drift to indicate where the probable end of drift will result. The probable end of drift is the location the snow drift will end in relation to the information entered by the user (including snow fence height and porosity) and the terrain data available on each specific cross section.

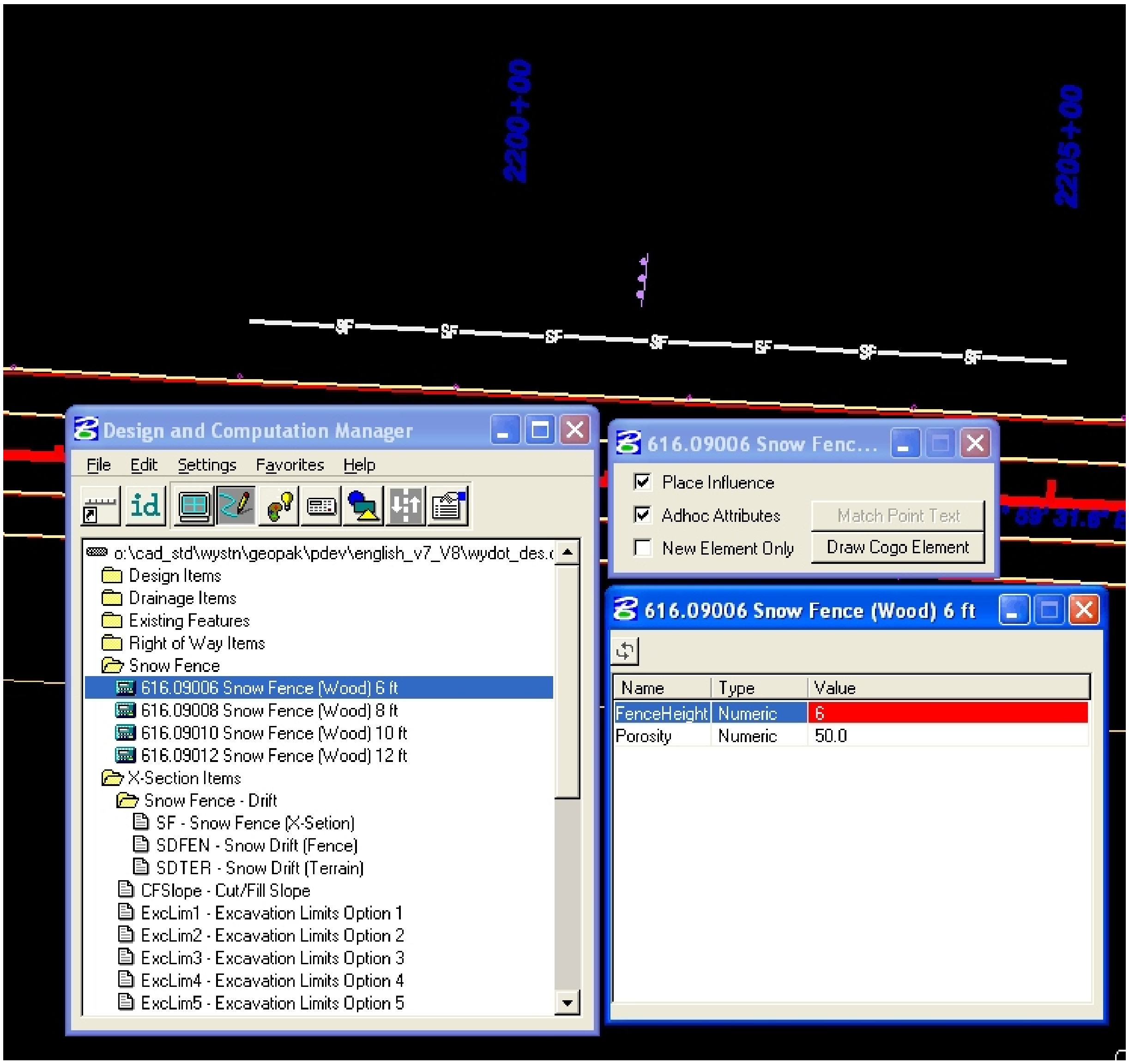
Adequate existing ground cross section length is essential in generating accurate drift profiles, see Appendix “A”, Algorithms for Generating Snow Fence Drift Profiles developed by R. D. Tabler (2006). Cross sections need to be generated parallel to the prevailing wind direction to produce a valid representation of drift characteristics. Prevailing wind direction is also essential in determining fetch distance and placement of snow fences.

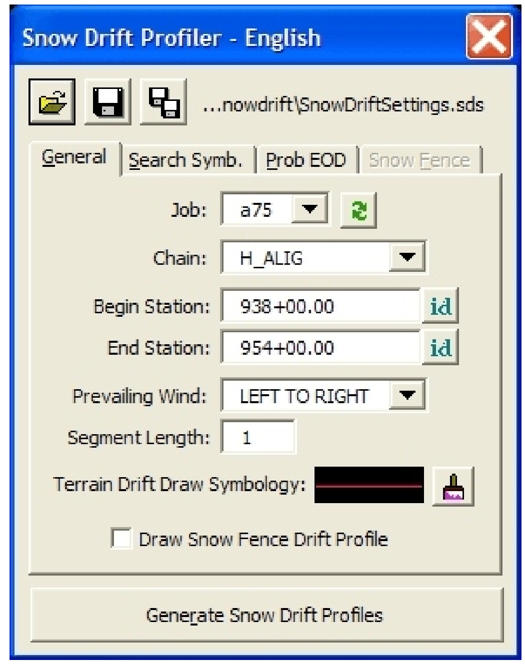


To use this tool, determine the prevailing wind direction for the given location (See Blowing Snow Explanation of Terms). Generally fences should be oriented parallel to the road if the prevailing wind direction is within 35º of being perpendicular to the road. For winds that are more oblique, fences should be aligned perpendicular to the prevailing wind direction. If required set the cross section pattern lines in the direction of the prevailing wind. Pattern lines will most likely be skewed to the roadway centerline. Cut the existing ground cross sections for the set pattern lines. Process the Proposed Cross Section run on the existing ground cross sections if a proposed roadway template is being reviewed at this location. If your pattern lines are skewed to your proposed alignment, toggle off “Remove Skew Effect” in the Plot Parameters options of your Proposed Cross Section run prior to processing that run. Turning off the “Remove Skew Effect” option will allow GEOPAK to plot the proposed cross section slopes relative to the skew resulting in a better drift prediction.

If you wish to review a proposed snow fence drift profile with the terrain drift profiles, place the appropriate proposed snow fence linestyle in the _pln.dgn file (plan view file) using the D&C manager. Select the appropriate snow fence type relative to the desired snow fence height in the D&C Manager. Four different fence heights may be selected 6', 8', 10', and 12'. Porosity will default to 50%, as previously stated, however may be changed to 0%, 25% 37.5% or 50%. To modify fence porosity the user will open the D & C Manager and select the height of snow fence desired. Once the snow fence has been selected the **Place Influence** box as well as the **Adhoc Attributes** boxes should be checked. After checking the **Adhoc Attributes** box a third pallet will become visible indicating fence height previously selected and porosity. The user can not modify fence height here however, the user can change the porosity.

Note, the user can input **any** porosity value however, an error message will appear when processing the snow drift if one of the four defaults are not selected. Place the proposed snow fence at the desired location after selecting height and porosity.





Open the _xsd.dgn (cross section) file where the cross sections are located. Verify that the Unit System in the GEOPAK User Preferences dialog box is set to the working units of the cross sections. Toggle the "Snow Drift" button on the primary tool bar to activate the WYDOT Snow Drift Profiler tool. The following Snow Drift Profiler tool will appear. Note the working units located next to the tool bar title. This value should correspond to the Unit System setting verified earlier. Also note that the General tab has already been partially completed. The Snow Drift Profiler tool populates this tab based on the current Working Directory setting in the GEOPAK User Preferences and the current _xsd.dgn file. Above the General tab are three button options and a "SnowDriftSettings.sds" file name. The three buttons from left to right allow the user to *Open Settings File, Save Settings* or *Save Settings to Another File*. The "SnowDriftSettings.sds" file name is the default settings file automatically created in the working directory. This file will hold the Snow Drift Profiler settings so they do not have to manually re-populate every time you return to this tool. If you review your working directory in Windows Explorer, you will see that the Snow Drift Profiler tool created the "SnowDriftSettings.sds" file in your working directory. If you wish to change the .sds settings file name to a more appropriate name relative to your project, utilize the Save Settings to Another File button and select another file name. You will need to delete the default "SnowDriftSettings.sds" once you have created your project .sds file. Multiple .sds files can be saved in the same working directory. You may need to review multiple snow drift locations on a single project. You will need to save your Snow Drift Profiler settings for each location in different .sds files. If you exit and return to the Snow Drift Profiler tool and wish to reload a specific .sds file, use the Open Settings button to select the desired .sds file. As you populate the Snow Drift Profiler tool, toggle the Save Settings button to ensure your current settings are saved. Failure to save your settings will result in the tool needing to be re-populated.

Upon closing the Snow Drift Profiler tool, you will be prompted to save settings. If you agree to save settings, the set values will be stored in the current .sds file shown right of the three buttons.

On the General tab, verify the Job. If you have a single .gpk file in your working directory and it is the .gpk file for the cross section file you have open, the job will be correct. If you have multiple .gpk files in your working directory, the correct job may not appear and the Chain, Begin Station and End Station options below the Job will not match your current _xsd.dgn file. Toggle on the Job pull down option to the right of the Job window to select your current job. If your Job does not appear in the pull down toggle, toggle the Refresh

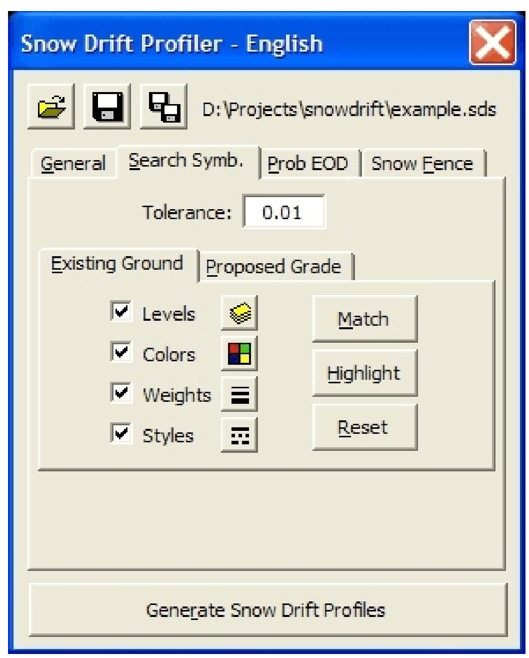
Job Number button right of Job pull down button, and then re-select the correct job. If your job number still does not appear, verify your Working Directory setting in your GEOPAK User Preferences. This Job settings is reading the Working Directory of the GEOPAK User Preferences if it is set, or your current working directory of the open _xsd.dgn file if the Working Directory is undefined in the GEOPAK User Preferences. Verify the Chain, Begin Station, End Station and Prevailing Wind direction settings.

The Segment Length option allows the user to control “at what increment” the drift profiles will be calculated. If this value is set to “1,” the drift profiles will be calculated every Master Unit of your _xsd.dgn file. Keep in mind as you change this value, the smaller the number, the more detailed your drift profiles will be and the longer it will take to calculate all the drift profiles. The default value is “1.”

The Snow Drift Profiler tool plots all “terrain drifts” prior to analyzing any proposed snow fences that may be placed in the _pln.dgn file. The Terrain Drift Symbology option controls how the existing terrain profiles will be plotted on the cross sections. The option may be set by toggling on the Paint Brush button to the right of the sample line window and then selecting the appropriate D&C Manager feature **(X-Section Items > Snow Fence - Drift > SDTER - Snow Drift (Terrain))**.

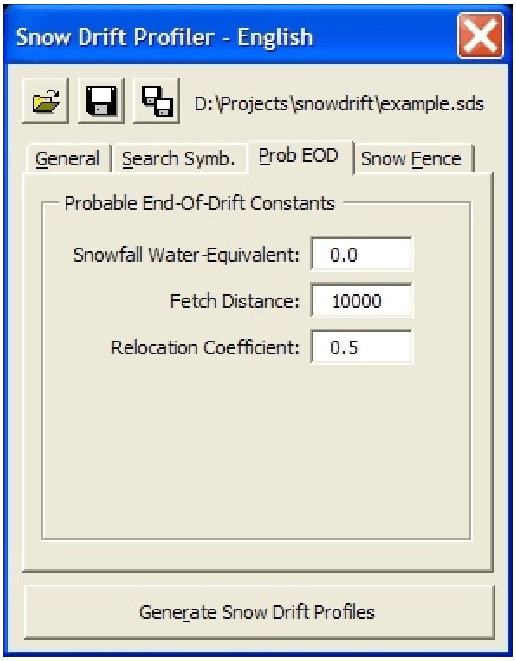
If you wish to have the Snow Drift Profiler tool analyze any proposed snow fences placed in your _pln.dgn file, you will need to toggle-on the Draw Snow Fence Profiles option. Note that the Snow Fence tab becomes available only after you activate the Draw Snow Fence Profiles option.

It is a good habit to toggle the Save Settings button at this time to save your current settings.



Toggle the Search Symbology tab. This tab reveals the Existing Ground and Proposed Grade symbology search tabs. The Tolerance option above the tabs is the same tolerance utilized throughout GEOPAK. This option allows the Snow Drift Profiler tool to consider gaps between MicroStation elements non-existent if the gap distance is less than or equal to the Tolerance value.

To set the Existing Ground and Proposed Grade tabs, toggle-on the Symbology options (Levels, Colors, Weights, Styles) you want the profiler tool to read. Toggle the Reset button to clear current values. Zoom-in to a cross-section and toggle the Match button and then select the appropriate element(s). You may review your selection by toggling the Highlight button. The Symbology options may also be set manually by selecting the appropriate button right of each option. Again, Save Settings.



If you selected the Draw Snow Fence Drift Profile option on the General tab and wish to have the Snow Drift Profiler tool calculate and mark the probable end of drift, toggle the Prob EOD tab to set some additional parameters required. The Prob EOD tab allows the user to enter additional information needed to calculate the probable end of drift or "average" drift length for the given terrain information and entered data. The probable end of drift will be marked with an arrow on the equilibrium snow fence drift profile. The values that need to be entered include Snowfall Water-Equivalent, Fetch Distance and Relocation Coefficient. The default values for Snowfall Water-Equivalent is zero, Fetch Distance is 20000 feet for English working units and 6000 meters Metric working units, and the Relocation Coefficient is 0.5. The default values will result in no probable end of drift arrow being placed on the equilibrium drift.

Wyoming Elevation-based Estimated
Snowfall Water-Equivalent Table

Elevation		Snowfall Water-Equivalent	
feet	meters	inches	meters
3300	1000	4	0.11
4100	1250	5	0.13
4900	1500	6	0.16
5700	1750	6	0.16
6600	2000	9	0.23
7400	2250	11	0.29
8200	2500	14	0.35
9000	2750	17	0.42
9800	3000	20	0.51
10700	3250	24	0.62
11500	3500	30	0.76
12300	3750	36	0.92
13100	4000	44	1.12

Tabler; Computer-Aided Design of Drift Control Measures, 1997

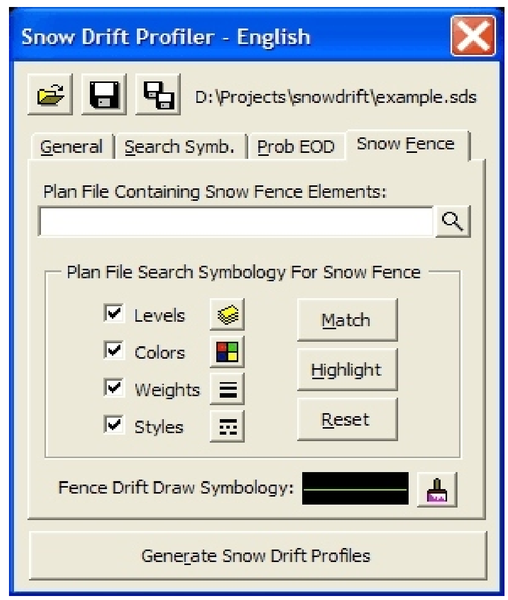
Snowfall Water-Equivalent is the depth of water (inches or meters) that would be generated from melting of snow received through the entire "snow accumulation season". A reasonable estimate for Snowfall Water-Equivalent is the total snow fall during the snow accumulation season divided by ten. A way to obtain a Snowfall Water-Equivalent value is the Wyoming Elevation-based Estimated Snowfall Water-Equivalent Table shown on the following page. Other options to obtain Snowfall Water-

Equivalent would be the WYDOT Winter Research Services office and National Climatologic Data Center Records.

The Fetch Distance (feet or meters) is the distance upwind of the snow fence where snow can be picked-up by the wind and relocated downwind. Forests, streams, rivers, tree rows, deep ravines, gullies, buildings and anything that may block snow from blowing or retain snow will define the fetch distance. Contact the WYDOT Winter Research Services office if you need assistance determining a Fetch Distance value.

The Relocation Coefficient defines the percentage of fallen snow that will be relocated from the upwind fetch area. This value may vary from 0.75 for barren, windy, cold locations to 0.15 for locations with dense tall vegetation. If the relocation coefficient is unknown, use the default value of 0.5. The WYDOT Winter Research Services office will assist in determining a Relocation Coefficient value.

This may be a good time to toggle the Save Settings button.



The Snow Fence tab is the location the user enters the plan file name where the proposed snow fence is drawn, sets the Plan File Search Symbology for the proposed snow fence, and sets the Fence Drift Draw Symbology option to control how the snow fence drift profiles are drawn on the cross sections. This tab will not be available unless the user has toggled-on the Draw Snow Fence Profiles option on the General tab.

The first option that needs to be completed is the Plan File Containing Snow Fence Elements window. The user may manually type-in the path and file name containing the snow fence elements, or the user may select the magnifying glass toggle to browse for the plan file.

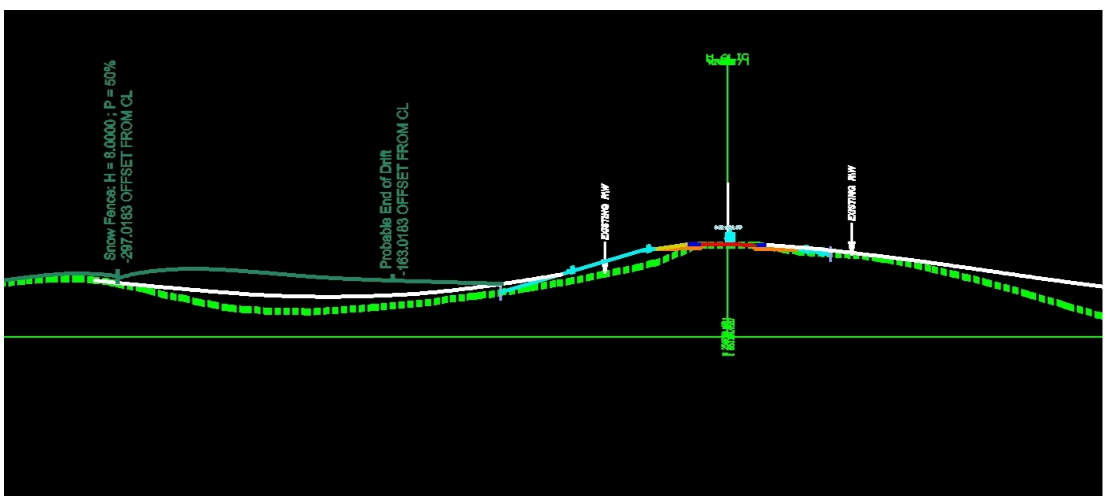
To set the Plan File Search Symbolgy For Snow Fence option, keep the Snow Drift Profiler tool running, open the plan file containing your proposed snow fence, toggle-on the symbology options (Levels, Colors, Weights, Styles) you want the profiler tool to read. Toggle the Reset button to clear current values. Zoom-in to a drawn snow fence, toggle the Match button and select the snow fence. You may review your selection by toggling the Highlight button. Return to the cross section file while keeping the Snow Drift Profiler tool active. The Search Symbology options may also be set manually by selecting the appropriate button right of each option.

Again, toggle Save Settings.

The Fence Drift Draw Symbology sets how your snow fence drift profile will be drawn. This option may be set by toggling on the Paint Brush button right of the sample line window and selecting the appropriate D&C Manager feature **(X-Section Items > Snow Fence - Drift > SDFEN - Snow Drift (Fence))**.

Once all parameters have been set in the Snow Drift Profiler tool, toggle the Generate Snow Drift Profiles button to begin processing the cross sections. The main Snow Drift Profiler tool will disappear, the plan file will be temporarily opened and closed returning to the cross section file, and the Cross Section Process Control window will appear. This window will allow the user to Begin the snow drift profile processing, Pause on each cross section during the processing, Abort the process at any time (if the Pause on each section toggle is selected), or physically Move Fence being drawn on the cross section (if the Pause on each section toggle is selected). To move a fence, toggle Move Fence and data on the cross section snow fence and drag it left or right. The entire snow fence drift profile (including the probable end of drift) is recalculated on the fly. The plan view snow fence is not being moved at this time. Once the user decides where the ideal snow fence location should be, the plan file snow fence will need to be relocated.

Below is an example of a processed cross section. Text included with the snow fence and profile drift indicates snow fence height, snow fence porosity and the offset distance from the roadway centerline. The probable end of drift text includes the offset distance from the roadway centerline. The white snow drift profile is the terrain snow drift profile. The snow drift profile attached to the snow fence is the snow fence drift profile.



Below is an example of the SnowDriftSettings.sds text file. As previously stated this file may be saved with a title specific to each snow fence area or used for an entire project.

```
************** DEFAULT VALUES FOR SNOWDRIFT VBA APPLICATION ****************
Job Number = a69
Chain Name = HOR
Beginning Station = 2124+00.00
Ending Station = 2758+00.00
Segment Length = 1
Prevailing Wind = 0
Tolerance = 0.01
Draw Fence Drift = N
Plan File Containing Fence Elements = D:\projects\snowdrift\a69z test\A69Z_pln.dgn
Snow-Water Equivalent = 10
Fetch Distance = 1000
Relocation Coefficient = 0.5
******* EXISTING GROUND SEARCH SYMBOLOGY *******
Level = ON
Levels = Level 20
Color = ON
Colors = 0,2
Weight = ON
Weights = 8
Style = ON
Styles = 2
******* PROPOSED GRADE SEARCH SYMBOLOGY *******
Level = ON
Levels = Level 15,Level 17,Level 23
Color = ON
Colors = 1,3,23,52
Weight = ON
Weights = 4
Style = ON
Styles = 0
******* PLAN FENCE SEARCH SYMBOLOGY *******
Level = ON
Levels = Level 24
Color = ON
Colors = 16
Weight = ON
Weights = 5
Style = ON
Styles = 399e
******* TERRAIN DRIFT DRAW SYMBOLOGY *******
Level = Level 45
Color = 0
Weight = 4
Style = 0
******* FENCE DRIFT DRAW SYMBOLOGY *******
Level = Level 45
Color = 59
Weight = 4
Style = 0
```

Information required by user:
1.) Fetch
2.) Porosity
3.) Prevailing Wind Direction
4.) Relocation Coefficient
5.) Snow Water-Equivalent

Blowing Snow Explanation of Terms and How to Obtain:

Questions regarding any of the following terms should either be directed to the WYDOT Winter Research Services Office or references by R. D. Tabler.

"Downwind Drift"	The snowdrift that forms on the downwind, or leeward, side of a snow fence or other object.
"Equilibrium Drift"	The snowdrift formed by a snow fence, terrain feature, or other barrier when filled to capacity for the existing wind conditions.
"Fetch"	The length of the area that is a source of blowing snow to a downwind location. The upwind end of the fetch is any boundary across which there is no snow transport, such as forest margins, deep gullies or stream channels, rows of trees, ice pressure ridges, and shorelines of unfrozen bodies of water. Fetch distances may be obtained from the WYDOT Winter Research Services, scaled from aerial photography, USGS maps, on-site visits or field personnel.
"Leeward Drift"	(Same as Downwind Drift)
"Porosity"	The voids or spaces between slats or rails, excluding the bottom gap. *In this document porosity is given as a percentage. The standard porosity for WYDOT snow fences is 0.50 (50%). Adequate research should be performed if a designer chooses to modify porosity. Less porosity will decrease the required setback distance,* for instance 0.25 porosity the acceptable setback would be 25H (25 times the fence height), 0.0 porosity acceptable setback equals 12H. There may be applications where a decrease in porosity is useful however, the user must be aware that a deviation from 0.50 will decrease trapping efficiency and could cause fences to be buried.

"Prevailing Wind Direction"	The mean wind direction that corresponds to the mean annual snow transport. Often referred to as Prevailing Direction of Snow Transport. Prevailing Wind Direction can be obtained from several sources including National Weather Service Stations at airports, Remote Weather Information Systems (RWIS), measured from snowdrifts late in the winter or observations of wind erosion on manmade and natural features. Information obtained from national weather stations and RWIS must be downloaded and analyzed. Manipulation of this data is time consuming and requires knowledge of the correct procedures to gain useable results however, is the most accurate method. Do to a limited number of locations where wind data is collected the user may need to rely on snowdrift features near the end of the snow accumulation season. A reliable hand held compass should be used to measure direction of drifting caused by bushes, trees, fences, buildings and any other features causing snow to drift. The user will stand at the feature and face the upwind direction the drift is formed. The WYDOT Winter Research Services office may be the best source of information for obtaining Prevailing Wind Direction.
"Relocation Coefficient"	The proportion of winter snowfall water-equivalent relocated by the wind. This will vary depending on vegetation. In cold windy locations with little or very short vegetation such as Wyoming the relocation coefficient seldom exceeds 0.70. In the northeastern part of the United States the relocation coefficient may be as low as 0.15.
"Setback"	The distance between the fence and the road shoulder, as measured in the direction of the prevailing wind.
"Snow Accumulation Season"	The season of drift growth, beginning with the first blowing snow event that causes drifts that persist through the winter, and ending when snowdrifts reach their maximum volume for the winter. Most locations in Wyoming the snow accumulation season begins around late October or early November and ends in late March or early April.

"Snow Water-Equivalent"	The depth of water, usually expressed in meters or inches that would result from complete melting of the snowfall or snow pack received through the entire snow accumulation season. For a conservative estimate the designer may use the Wyoming Elevation-based Estimated Snowfall Water-Equivalent Table included in this document.
Upwind Drift"	The snowdrift that forms on the upwind, or windward, side of a snow fence or other object.
"Windward Drift"	(Same as Upwind Drift)

The preceding instructions were compiled by Chuck James, Blowing Snow Research Team, Wyoming Department of Transportation. Email: chuck.james@dot.state.wy.us

References:

Tabler, R. D. 2006. *Algorithms for Generating Snow Fence Drift Profiles*. Tabler & Associates, Niwot, CO. 11 pp.

Tabler, R. D. 1997. *Computer-Aided Design of Drift Control Measures.* Research Project # FHWA-WY-97/02, Federal Highway Administration and Wyoming Department of Transportation. 47.

Tabler, R. D. 2003. *Controlling Blowing and Drifting Snow with Snow Fences and Road Design,* National Cooperative Highway Research Program, NCHRP Project 20-7(147).

APPENDIX A:

Algorithms for Generating Snow Fence Drift Profiles

revised February 7, 2006

Ronald D. Tabler

ALGORITHMS FOR GENERATING SNOW FENCE DRIFT PROFILES
Revised February 7, 2006
Ronald D. Tabler

Introduction

This narrative describes the algorithms used to predict the cross-section of snowdrifts, as measured parallel to the wind, formed by snow fences in irregular terrain. Input data consist of distances and elevations along a transect parallel to the wind, and the structural height, porosity, and location of one or more snow fences. **An essential requirement is that the 45 m of the topographic section farthest upwind must not be in a snow deposition area; i.e., the snowdrift depth over the first 45 m of the transect must be known to be zero (Figure 1)**. The generated snowdrift profile is that resulting from an unlimited supply of blowing snow so that terrain features and snow fences have been filled to capacity; i.e., the snowdrifts are at *equilibrium*. Because of the downwind progression of drift growth, whereby an upwind sink for blowing snow must be filled before a drift begins to form in the next deposition area downwind, the equilibrium snowdrift profile is generated incrementally in a downwind direction. It is therefore possible to truncate the generated profile when the accumulated mass of blowing snow equals the estimate for actual snow transport at the site being analyzed.

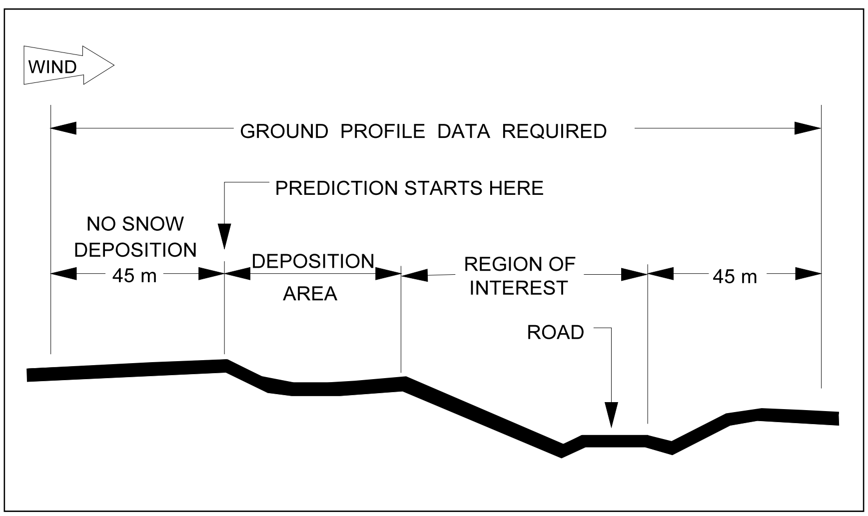


Figure 1. Ground profile data required to generate the snowdrift profile in the region of interest (from Tabler 1994).

The procedure described here is a modification of the method developed in 1976 by R. D. Tabler (1975a) for the Wyoming Snowdrift Prediction System, as described by R. H. Christensen (1976). The changes from the original version are noted in the narrative. The step-wise procedure is as follows:

1. Generate the snowdrift profile caused by terrain features, without snow fence(s), up to and including the location of the first snow fence from the upwind end of the transect.

2. For a given structural fence height (H_s) at a specified location, determine the effective height of the fence (H_e) above the snow surface generated in Step 1 (calculated as H_s minus the snowdrift depth).

3. Generate the drift on the upwind side of a snow fence of height H_e (this drift is generated on top of the topographic drift from Step 1).

4. Generate the drift on the downwind side of the fence (this drift is generated over the ground surface, not the topographic drift surface).

5. For a second row of fence, calculate the effective fence height relative to the snowdrift surface generated by the first row of fence, and generate the upwind drift on top of the drift formed by the first fence. The downwind drift is generated over the ground surface. Additional fences can be analyzed by repeating the same procedure.

STEP 1: Topographic Snow Surface

The first step is to generate the snowdrift profile that would result from terrain features without snow fences, here referred to as the "*topographic snow surface*." As described in the publication *Design Guidelines for the Control of Blowing and Drifting Snow* (Tabler 1994), this procedure utilizes the algorithm for estimating the slope of the snow surface over an increment of distance (typically 0.1 m) downwind from a point

$$m_5 = 0.25m_1 + 0.55m_2 + 0.15m_3 + 0.05\, m_4 \tag{1}$$

$$\text{if calculated } m_2, m_3, \text{ or } m_4 < -0.20, \text{ set } m_2, m_3, \text{ or } m_4 = -0.20$$

where m_5 = slope of the snow surface over the next increment of distance,

m_1 = the mean slope from 45 m upwind to the point where the next increment of the drift surface is being generated,

m_2 = the mean slope from the point to a point 15 m downwind,

m_3 = the mean slope from the point 15 m downwind to a point 30 m downwind,

m_4 = the mean slope from the point 30 m downwind to a point 45 m downwind.

Slopes upward in the direction of the wind are taken as positive, and downward slopes as negative. The mean slope is calculated as the difference in elevation from the initial point to the terminal point divided by the horizontal distance between the points. Slope m_1, referred to as the approach slope because it is upwind of the point at which the surface slope is being computed, is computed from the last calculated point on the snow surface to the generated snowdrift surface 45 m upwind (Figure 2). Slopes m_2, m_3, and m_4 are referred to as "exhaust slopes." Slope m_2 is computed from the last calculated point on the snow surface to the ground, and slopes m_3 and m_4 are determined from the ground (topographic) surface. The maximum negative exhaust slope is –0.20; i.e., if the computed value is less than this value, -0.20 is used in determining the slope of the snow surface.

The slope of the snow surface, m_5, multiplied by the horizontal incremental distance, is added to the snow surface elevation at the previous point to determine the elevation of the next point on the surface. This value is compared to the ground elevation at the point and if the computed surface would fall below the ground surface, it is set equal to the ground surface.

Total mass of snow along a transect is calculated by accumulating the mass of snow contained in each increment of distance using the relationship

$$\rho_{ave} = 522 - [304/(1.485Y_{ave})][1-exp(-1.485Y_{ave})] \qquad (2)$$

where ρ_{ave} is average snow density (kg/m^3) over the increment, Y_{ave} is the average vertical depth over the increment, and $exp(-1.485Y_{ave})$ is the base of the natural logarithms (2.718…) raised to the $(-1.485Y_{ave})$ power (Tabler 1994). The notation convention $exp(X) \equiv e^X$ will be used throughout the remainder of this narrative. By comparing the accumulated mass to the estimated snow transport at the site (Tabler 1975b; 1994) it is possible to estimate the probable end of the drift where the estimated snow surface could be truncated rather than generating the equilibrium profile for unlimited snow transport.

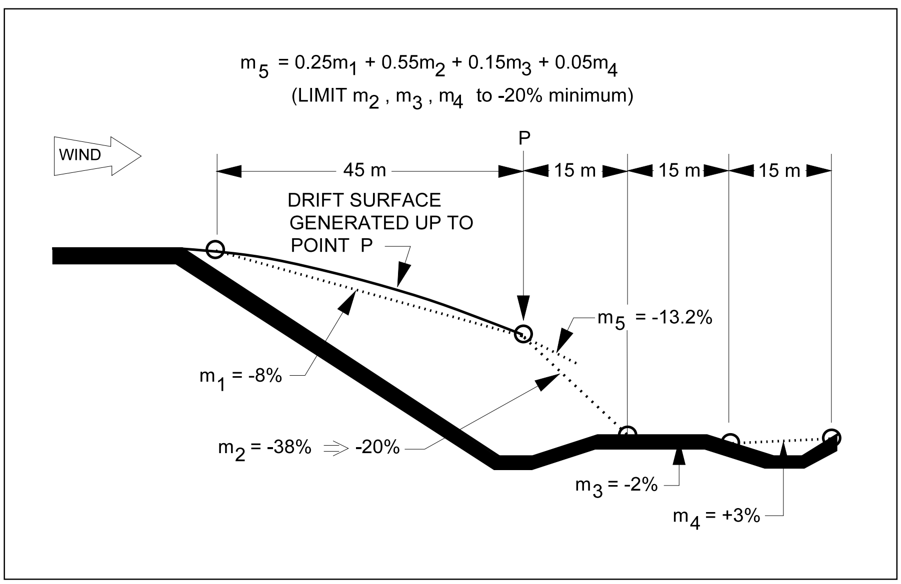


Figure 2. Examples of distances and slopes used in Equation (1) to estimate the slope of the next snow profile increment (after Tabler 1994).

STEP 2: Calculate Effective Fence Height

The effective height (H_e) of a snow fence at a specified location is calculated by subtracting the snow depth (Y) determined in Step 1 from the structural fence height (H_s):

$$H_e = H_s - Y \qquad (3)$$

Where $Y>H_s$, the fence is buried by the topographic snowdrift and is ignored in subsequent calculations. Locations for snow fences should be selected to avoid burial that can cause structural damage to the fence as well as reducing the snow storage capacity of the fence.

STEP 3: Generate Drift on Upwind Side of Fence

The algorithm for estimating the upwind drift has been completely revised from the original version described by Christensen (1976). In the present algorithm, the approach slope for a snow fence, m_a, is defined as the mean slope of the topographic snow surface between the fence and a point 45 m upwind (Figure 3). An uphill approach is the case where the wind is blowing uphill toward the fence (m_a positive), and a downhill approach is where the terrain slopes in the opposite direction. The snow profile on the windward side of the fence having effective height H_e is approximated by a polynomial equation

$$Y_u/H_e = \gamma A_u + B_u(d_s) + C_u(d_s)^2 + D_u(d_s)^3 + E_u(d_s)^4 + F_u(d_s)^5; \qquad d_s < Limit \qquad (4)$$

where Y_u is the drift depth above the topographic snow surface measured normal to the approach slope; d_s is (distance from the snow fence measured along the approach slope plane)/H_e; and the coefficients A_u, B_u, C_u, D_u, E_u and F_u, and the limit of applicability, vary with fence porosity as given in Table 1. γ is a slope correction factor that is unity for flat terrain or a downhill approach, but varies with an uphill approach (i.e., wind blowing uphill toward the fence) according to

$$\gamma = exp(-6m_{au}); \quad m_{au} > 0 \qquad (5)$$

The coefficient for m_{au} (6) was determined empirically from measured drift profiles. The original algorithm described by Christensen (1976) assumed a linear approximation to the profile starting at a point 10H upwind of the fence, and extending to the midpoint or top of the fence, depending on the approach slope. If Y_u/H_e, as calculated from Equation (4), is negative, it should be set equal to zero.

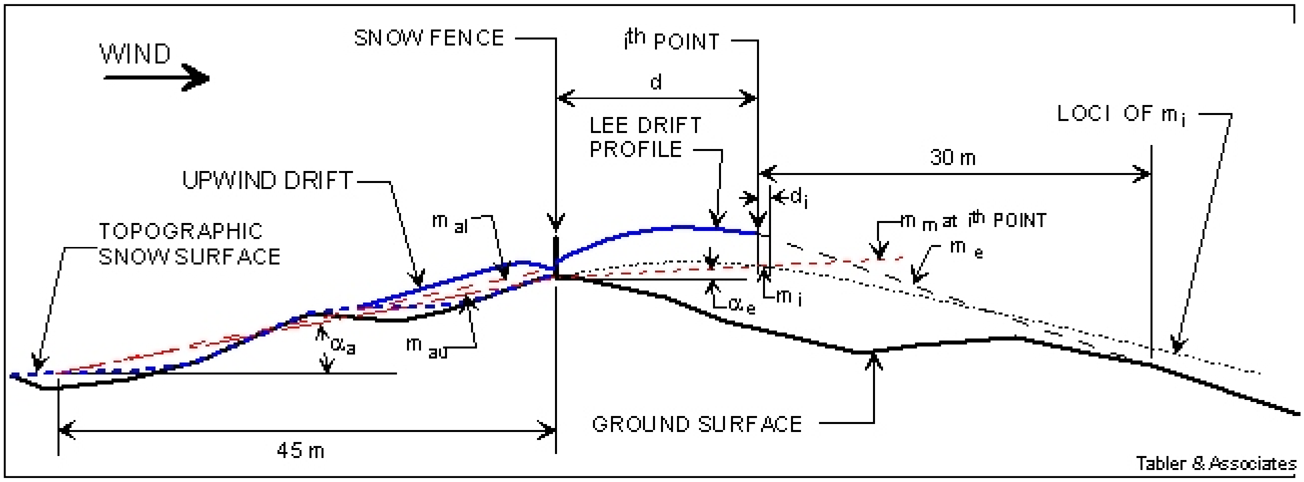


Figure 3. Illustration of slopes used to generate the snow fence drift profiles (revised).

Table 1. Coefficients and limits of applicability for upwind drift polynomials (Equation 4) for fences with indicated porosities.

% Porosity	A_u	B_u	C_u	D_u	E_u	F_u	Limit for d_s
0	9.13E-01	-3.610E-01	1.0050E-01	-1.8790E-02	1.7830E-03	-6.4000E-05	<10
25	6.30E-01	-1.450E-01	1.9240E-02	-1.2975E-03	7.5800E-06	1.8028E-06	<12
37.5	5.75E-01	-7.600E-02	4.4025E-04	6.8276E-04	-5.9656E-05	1.5934E-06	<15
50	5.20E-01	-5.540E-03	-2.1701E-02	3.5524E-03	-2.2153E-04	4.8560E-06	<16

The vertical snow depth above the topographic snow surface is given by

$$Y = Y_u / \cos \alpha_a \qquad (6)$$

where α_a is the approach slope angle ($\alpha_a = \tan^{-1} m_{au}$). The elevation of the snow surface at a given point is computed as the vertical snow depth plus the elevation of the topographic snow surface at the point.

The effect of snow fence porosity on drift geometry is illustrated for the case of flat terrain in Figure 4. The original version of this algorithm (Christensen 1976) was restricted to a fence porosity of 50%.

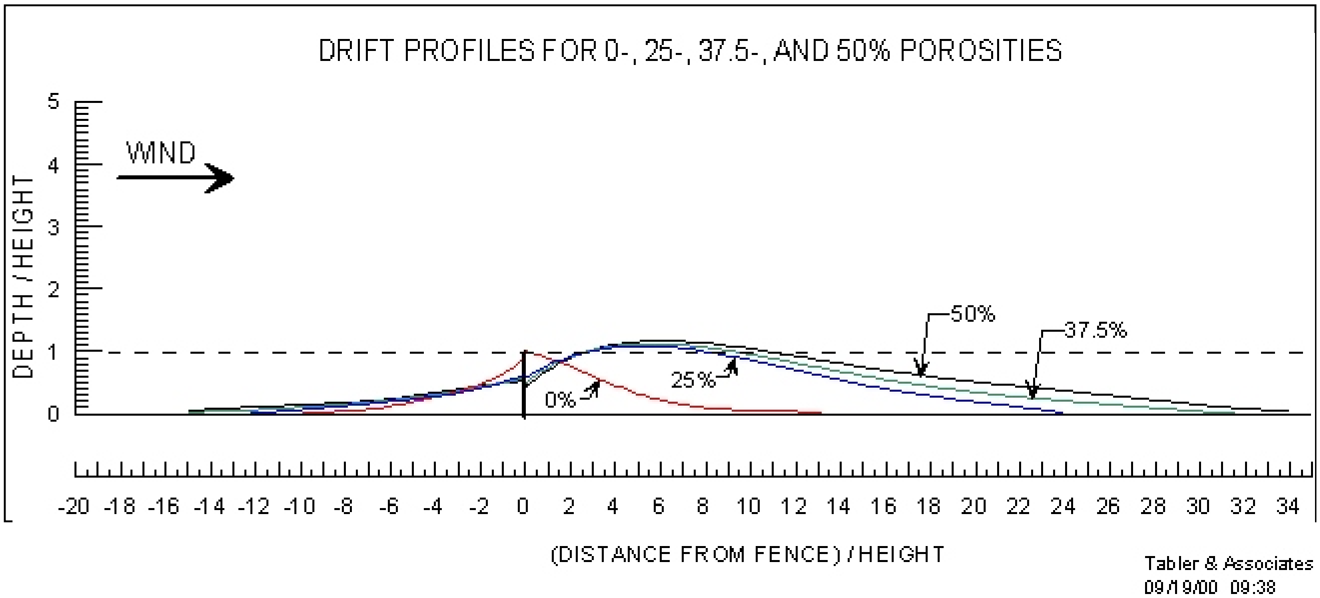


Figure 4. Effect of snow fence porosity on shape of upwind and lee drifts on flat terrain, as given by Equations (4) and (10) and the values presented in Tables 1 and 3 (Tabler 2003).

STEP 4: Generate Drift on Downwind Side of Fence

The leeward drift is generated over an "*effective slope"* that combines the effect of the approach slope upwind of the fence and the exhaust slope from the last point on the generated drift surface to the ground 30 m downwind. As with the exhaust slopes in Equation (1), m_e is limited to values $\geq$ -0.20. In addition, however, m_e is also limited to values less than, or equal to, zero. For each increment of distance downwind from the fence, d_i, an effective slope, m_i, is computed as

$$m_i = m_e(1-t) + m_{al}\, t \tag{7}$$

where m_e is the mean slope from the last point on the generated snow surface to a point on the ground 30 m downwind, m_{al} is the approach slope 45 m upwind from the fence determined from points on the upwind drift profile generated in Steps 1 and 3, and t is an exponential decay function

$$t = exp[-d/(\varepsilon H_e)] \tag{8}$$

where d is horizontal distance downwind from the fence (Figure 3), and ε is a coefficient that varies with fence porosity as shown in Table 2. As distance d increases, the effect of the approach slope diminishes in a fashion analogous to a fading memory, and the influence of the exhaust slope increases. Values for ε were determined empirically as that providing the best fit to measured snowdrift profiles.

Table 2. Values for ε in Equations (8) and (11) for different fence porosities.

Porosity(%)	ε
0	3.5
25	17
37.5	20
50	20

The average of the incremental effective slopes from the fence to the point being estimated, m_m, defines the plane of the effective slope upon which the next increment of the lee drift profile is constructed, and is calculated as

$$m_m = \frac{1}{j}\sum_{i=1}^{j} m_i \tag{9}$$

where j is the number of increments over distance d.

The depth of the lee drift at the end of the increment of surface being generated is estimated from a polynomial equation similar to Equation (4):

$$Y_L/H_e = \delta A_L + B_L(d_s) + C_L(d_s)^2 + D_L(d_s)^3 + E_L(d_s)^4 + F_L(d_s)^5; \quad d_s < Limit \tag{10}$$

where Y_L is the drift depth above a plane defined by the mean effective slope, m_m, measured normal to the slope; d_s is (distance from the snow fence measured along the plane of the mean effective slope)/H_e; and the coefficients A_L, B_L, C_L, D_L, E_L and F_L, and the limit of applicability, vary with fence porosity as given in Table 3. δ is a slope correction factor similar to γ that is unity for flat terrain or a downhill approach, but varies with an uphill approach (i.e., wind blowing uphill toward the fence) according to

$$\delta = 1 - t + exp[-6m_{au} - d/(\varepsilon H_e)]; \quad m_{au} > 0 \tag{11}$$

The original algorithm described by Christensen (1976) did not include an adjustment for uphill approach, and was limited to a fence porosity of 50%.

Distance d_s is given by

$$d_s = d/(H_e cos\ \alpha_e) = d/[H_e cos(arctan\ m_m)] \tag{12}$$

If Y_L/H_e, as calculated from Equation (10), is negative, it should be set equal to zero.

Snow depth, Y_L, is converted to a vertical dimension and adjusted for the height of the effective slope from the relationship

$$S_p = Z_f + Y_L/cos\ \alpha_e + d_i\Sigma m_i \tag{13}$$

where S_p = the elevation of the snow surface at the point,
Z_f = the ground elevation at the fence,
α_e = the effective slope angle
Σm_i = the summation of incremental effective slopes downwind of the fence to the point.

The resultant value is compared to the ground elevation at the point and if the computed surface would fall below the ground surface, it is set equal to the ground surface.

When the limit of applicability for Equation (10) is reached, e.g., when d_s = 34 for the case of a 50%-porous snow fence, the snow surface over the remainder of the transect is generated using Equation (1). If a second row of snow fence is to be analyzed, the snowdrift profile is terminated at the location of the second fence, provided that the second fence is not buried by the upwind fence's profile (see STEP 2).

Table 3. Coefficients and limits of applicability for lee drift polynomials (Equation 10) for fences with indicated porosities.

% Porosity	A_L	B_L	C_L	D_L	E_L	F_L	Limit for d_s
0	1.00E+00	-8.100E-02	-3.2520E-02	5.8280E-03	-3.2840E-04	5.7400E-06	<13.2
25	5.80E-01	2.218E-01	-2.9048E-02	1.0150E-03	-1.4489E-06	-3.4199E-07	<24
37.5	5.02E-01	2.689E-01	-3.7588E-02	1.9275E-03	-4.4983E-05	3.9880E-07	<31.6
50	4.30E-01	3.016E-01	-4.1203E-02	2.1930E-03	-5.4209E-05	5.1050E-07	<34

STEP 5: Generate Drift for Multiple Rows of Fence, If Applicable.

To predict the snowdrift formed by a second snow fence downwind from the first, the drift on the downwind side of the first fence is terminated at the location of the second fence. The snow depth at this point is used to calculate the effective height of the second fence, and the upwind drift formed by the second fence is generated on top of the drift resulting from Step 4. The lee drift formed by the second row of fence is generated over the ground surface. If a third row of fence is involved, the lee drift behind the second fence must be terminated at the third fence, and so on.

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Notation

A_u = constant in polynomial expression for upwind drift

A_L = constant in polynomial expression for lee drift

B_u = coefficient in polynomial expression for upwind drift

B_L = coefficient in polynomial expression for lee drift

C_u = coefficient in polynomial expression for upwind drift

C_L = coefficient in polynomial expression for lee drift

d = horizontal distance from snow fence

d_i = distance increment used for profile generation

d_s = [distance from snow fence as measured along approach slope (upwind drift) or effective slope (lee drift)]/H_e
= $d/(H_e \cos \alpha_a)$ for upwind drift
= $d/(H_e \cos \alpha_e)$ for lee drift

D_u = coefficient in polynomial expression for upwind drift

D_L = coefficient in polynomial expression for lee drift

E_u = coefficient in polynomial expression for upwind drift

E_L = coefficient in polynomial expression for lee drift

$exp(\ ) \equiv e^{(\ )}$

F_u = coefficient in polynomial expression for upwind drift

F_L = coefficient in polynomial expression for lee drift

H_s = structural fence height

H_e = effective fence height
$= H_s - Y$

m_{au} = approach slope from a point 45 m upwind to the ground or snow surface at the fence, as determined from points on the topographic snow surface generated in Step 1.

m_{al} = approach slope from a point 45 m upwind to the snow surface at the fence, as determined from points on the surface of the upwind drift generated in Step 3.

m_i = incremental effective slope at a point downwind of a fence.
$= m_e(1\text{-}t) + m_a t$

m_m = average incremental effective slope

$$= \frac{1}{j}\sum_{i=1}^{j} m_i$$

m_1 = mean slope from 45 m upwind to the point where the next increment of the drift surface is being generated by the topographic algorithm (Equation (1))

m_2 = mean slope from the prediction point to a point on the ground surface 15 m downwind

m_3 = mean ground slope from the point 15 m downwind to a point 30 m downwind

m_4 = mean ground slope from the point 30 m downwind to a point 45 m downwind

m_5 = slope of the snow surface over the next increment of distance, as generated by the topographic algorithm (Equation (1))

S_p = elevation of the snow surface at the prediction point,

t = decay function for weighting influence of approach slope on effective slope
$= exp[-d/(\varepsilon H_e)]$

Y_u = upwind drift snow depth above topographic snow surface, measured normal to the slope

Y_L = lee drift snow depth above effective slope, measured normal to the slope

Y = total vertical snow depth at a point

Y_{ave} = average vertical snow depth (m) over an increment of distance, d_i

Z_f = ground elevation at the snow fence being analyzed

α_a = approach slope angle

α_e = the effective slope angle

γ = coefficient to adjust A_u in Equation (4) for uphill approach
$= exp(-6m_{au})$

δ = fading memory coefficient to adjust A_L in Equation (10) for uphill approach
$= 1 - t + exp[-6m_{au} - d/(\varepsilon H_e)]$

ε = coefficient which varies with porosity as shown in Table 2.

ρ_{ave} = average snow density (kg/m^3) over an increment of distance d_i