



Living Snow Fence Design

The design of living snow fences involves several components. This fact sheet offers a general protocol for the basic elements of design: Fence Orientation, Snow Fall, Fetch Distance, Snow Transport, Required Height, Selecting a Design Age, Optical Porosity, Fence Capacity, and Setback. The general guidelines presented here are adapted from “*Controlling blowing and drifting snow with snow fences and road design*” (Tabler, 2003), and “*Climatological analysis for snow mitigation in New York State*” (Tabler, 2000). It is recommended that these sources be consulted to supplement the basic information provided in this fact sheet. After the site assessment phase has sufficiently identified the blowing/drifting snow problem at a site (see Fact Sheet #2 of this series and Chapter 4 in Tabler 2003), the steps in this fact sheet can be followed in the order in which they are presented to create a basic living snow fence design to address the problem. A case-study example from a real living snow fence designed using this step-by-step protocol is provided at the end of the fact sheet. Models from Tabler (2003) were created in metric units and all equations in this fact sheet require all inputs to be in metric units to obtain valid results.

Step 1: Determine Fence Orientation

Snow fences should be oriented according to the direction of the prevailing winter wind relative to the roadway. The direction of prevailing wind can be highly localized, and it is recommended that direction be determined based on site-specific observations such as the direction of blowing snow across the road, or the direction of drifts formed around sign posts or other objects on the site. Wind direction can be more precisely quantified using a data logging anemometer. Once wind direction is determined, the orientation of the fence is selected based on the acute angle (α) of the wind direction relative to the roadway. In most cases, the acute angle (α) will be between 55° and 90° (Figure 1), in which case fences should be oriented parallel to the road. In some cases, the acute angle (α) will be less than 55° . In this case fences may need to be oriented perpendicular to the wind (Figure 2).

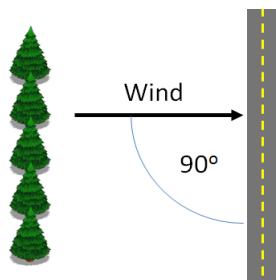


Figure 1 - Acute angle (α) is between 55° and 90° , fence is oriented parallel to the roadway
Diagram by SUNY ESF

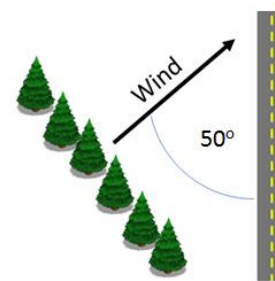


Figure 2 - Acute angle (α) is less than 55° , fence is oriented perpendicular to the wind
Diagram by SUNY ESF

Fences should be designed without any gaps, to provide continuous protection of the roadway. If a continuous fence is not possible due to site obstructions, fences can be designed in multiple sections that are slightly offset and overlapped by approximately 20 feet to prevent blow through between sections. If planting is not possible in certain areas due to obstructions such as a pavement or a drainage ditch,



structural snow fence segments can be used in conjunction with living snow fences to close gaps and prevent blow-through in these areas.

Step 2: Estimate Snowfall Water Equivalent over the Drift Accumulation Season (S_{we})

An estimate of the snowfall water equivalent over the drift accumulation season (S_{we}) is the first of two critical inputs for determining the quantity of blowing snow at a site (step 4). “Water equivalent” refers to the mass of liquid water equivalent of fallen snow, snow having a lower density than water. Note that S_{we} is different than the annual snowfall total for an area, the former being delimited by snow that falls before or after sustained drift growth occurs (Tabler, 2003). S_{we} in New York State can be calculated using the following equation from Tabler (2000):

$$S_{we} = (-695.4 + 0.076 * \text{Elev} + 17.108 * \text{Lat}) (0.0254) (0.10)$$

Where:

S_{we} is the water equivalent of snowfall over the drift accumulation season in meters

Elev is the elevation of the snow fence site in meters

Lat is the degrees north latitude of the snow fence site

Note that (0.10) represents the assumed water equivalent of snowfall. If the water equivalent of snowfall is known to be different at the snow fence site, this value can be adjusted accordingly. This equation applies only to New York State and S_{we} in other regions must be measured or estimated using other methods.

Step 3: Measure Fetch Distance (F)

Measuring the fetch distance provides the second critical input for determining the quantity of blowing snow in step 4. Fetch distance (F) as defined by Tabler (2000) as “... the distance contributing blowing snow to a downwind location. The upwind extent of the fetch is marked by some topographic feature across which there is no appreciable snow transport such as a wooded area... that causes blowing snow to be deposited.” (Figure 3). Fetch measurements must taken in (or converted into) metric units of meters and can be measured using mapping software or a field survey.

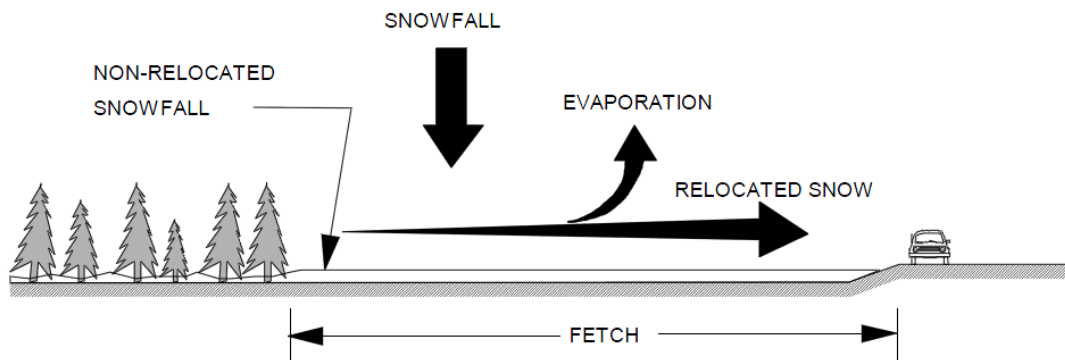


Figure 3 – Fetch distance for design of living snow fences
Source: Tabler (2000)



Step 4: Calculate Snow Transport (Q)

Snow transport (**Q**) is the quantity of blowing snow at a site over the drift accumulation season. Calculating **Q** provides an estimate of the quantity of blowing snow that will encounter the fence in an average year. **Q** is measured in units of metric tons of snow per linear meter of fence, abbreviated “t/m”. The following equation by Tabler (2000) provides an output for **Q**:

$$Q = (1500)(0.17)(S_{we})(1-0.14F^{3000})$$

Where:

Q is the average annual quantity of snow transport in units of t/m

(S_{we}) is the water equivalent of snowfall in meters from Step 2

F is the Fetch distance in meters from Step 3, with a maximum value of 3000

Note that (0.17) is the assumed relocation coefficient, or the percentage of fallen snow transported by the wind. This value is a statewide average recommended for snow fence design in New York by Tabler (2000). If a different value is known or measured at a site, it can be used in place of 0.17. The relocation coefficient in other regions outside of New York State may be substantially higher, and a climatic study should be conducted to determine an appropriate value for each region.

Step 5: Calculate Required Height (H_{req})

The required height (**H_{req}**) of the living snow fence in meters, based on the estimate of snow transport (**Q**) from Step 4, is calculated using the follow equation from Tabler (2003):

$$H_{req} = (Q/8.5)^{0.455}$$

Where:

H_{req} is the required minimum height of the snow fence in units of meters

Q is the quantity of snow transport in units of t/m from Step 4

This equation calculates the *minimum* height of the fence that is required to capture the snow transport (**Q**) in an equilibrium (maximum capacity) drift with a downwind drift length of approximately 35 times the required height (35**H_{req}**). Snow transport in any given year may exceed the average (**Q**), which will increase the **H_{req}** output of this formula. The height of living snow fences is not static, and increases over time as plants grow. Based on estimates of statewide **Q** values (Tabler 2003), most tree and shrub species recommended for living snow fences in New York State will exceed **H_{req}** early in their lifecycle (Heavey, 2013).

Refer to Fact Sheet #4 of this series (“*Species Selection*”) for recommended species, mature heights, and growth rates. Selecting a species that will exceed the required height will increase snow storage capacity of the fence, and reduce the length of the downwind drift over time. Note that this equation provides the required height on level ground. Terrain sloping down toward the road will increase the storage capacity



while terrain sloping up toward the road will reduce storage capacity, resulting in a potential decrease or increase in H_{req} , respectively. The influence of topography can be modeled using the “SNOWMAN” (Snow Management) software developed by NYSDOT and the University of Buffalo for Bentley MicroStation CAD.

Step 6: Select a Species and Design Age (a)

Because the variables of height, porosity, capacity, and drift length of living snow fences change over time, selecting a design age (**a**), which corresponds to a value for each of these variables, is a useful step in the design process. The estimated Porosity and Height (Steps 7 and 8) at the chosen design age will depend on the species that is selected for planting. Design age can be selected based on the type and species of vegetation used.

Examples of design ages would be 4 years (**a** = 4) when a fast growing shrub species is expected to begin trapping snow, 8 years when the same fence is expected to double in height from age 4, or 15 years when the fence is expected reach its full mature height. Modeling several different design ages can provide an estimate of how the function of the fence will change over time, and inform the important design decision of setback distance. Selecting one design age to start with in the current step provides a starting point for modeling the function of a living fence over time.

Step 7: Estimate Optical Porosity (P) in the design age

Porosity is the percentage of area not obstructed by vegetation when a fence is viewed at a perpendicular angle during winter. This concept is illustrated in Figure 4, showing a photograph taken at a 90° angle of a shrub-willow living snow fence in winter. The percentage of open space (in red), not blocked by vegetation, is the optical porosity (**P**). In this photo of a 6 year old shrub-willow fence, the Porosity is 57 percent (43 percent density). A living snow fence with 50 percent porosity has the highest amount of snow storage capacity. Living snow fences with porosity above 70 percent are ineffective at trapping snow. Fences with porosity below 50 percent have less snow storage capacity, but cause a higher percentage of snow to be stored on the upwind side of the fence, shortening the length of the downwind drift. A common target range for porosity when designing a living snow fence is between 40 to 60 percent.

As with fence height, porosity of living snow fences is not static. Porosity generally decreases with time as plants grow and fill in the open space. The porosity that a living snow fence will reach and the time frame will depend on the choice of species, plant spacing, and number of rows. Using smaller spacing between plants and multiple offset rows of vegetation will achieve the target porosity range of 40 – 60 percent more quickly. To reach the target porosity of 40 – 60 percent in an acceptable time frame, the following general guidelines for design can be used to select a planting pattern for general vegetation types of species recommended for living snow fences:



Evergreen Trees: 6 to 8 feet spacing between trees, two offset rows, 6 to 8 feet spacing between rows
Shrubs: 3 to 4 feet spacing between plants, two offset rows, 3 to 4 feet spacing between rows
Shrub-willows: 2 feet spacing between plants, two offset rows, 2.5 feet spacing between rows



Figure 4 – Photo of a shrub-willow living snow fence in winter. Plant stems are pictured in the foreground, in front of a red backdrop highlighting the optical porosity (open space) of the fence
Image by SUNY ESF

For evergreen trees and shrubs, the planting pattern also depends on the size of planting stock used. Planting large trees and shrubs will achieve the target porosity more quickly than smaller planting stock or seedlings planted at the same spacing. Use species specific information as much as possible and refer to the other fact sheets in this series (#4 “*Species Selection*”, and #6 “*Planting*”) for more guidelines on recommended species and planting techniques. Visiting living snow fences planted in previous years is also a good way to understand the change in porosity over time.

These guidelines should allow the design team to estimate a target porosity value that is expected at the chosen design age (**a**) from Step 6, or a default value of 0.50 can be used in the next steps of design. It is also important to remember that some vegetation types and planting pattern combinations, such as double rows of evergreen trees, will begin to act as non-porous barriers as they mature, with the result being that the majority of snow is stored on the upwind side of the fence, and the length of downwind drift is reduced (Tabler, 2003). Porosity data collected from numerous living snow fences of various vegetation types and ages is depicted in the scatter plot and regression equation shown in Figure 5, which can also be used to estimate porosity at a chosen design age.

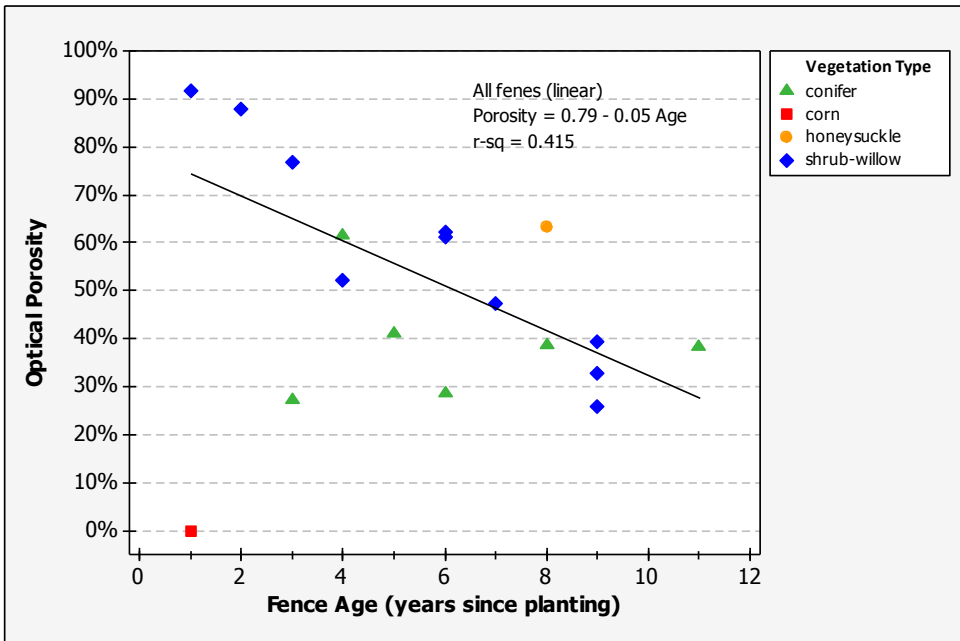


Figure 5 - Fence age versus optical porosity (P) of 18 living snow fences of various species in New York State.
Diagram by Heavey (2013)

Step 8: Estimate Height (H) and Fence Capacity (Qc) in the design age

It is important to remember that with living snow fences, height increases and porosity decreases over time. As height increases, storage capacity of the fence also increases in a similar trend. As porosity decreases below 50 percent, capacity decreases, but a higher percentage of snow is stored on the fences upwind side. Height at the design age can be estimated based on the chosen species and known growth rates of that species or vegetation type (refer to fact sheet #4 in this series "Species Selection"), or from the scatter plot and regression equation in Figure 6.

Once the estimated height and porosity in the design age have been determined, the snow storage capacity of the fence (Qc) in the design age can be modeled using the following equation from Tabler (2003):

$$Q_c = (3 + 4P + 44P^2 - 60P^3) H^{2.2}$$

Where:
Q_c is the snow storage capacity of the fence in units of t/m
P is the estimated porosity at the design age (a) from Step 7
H is estimated height at the design age (a) in meters



Storage capacity (Q_c) can then be compared to snow transport (Q) from Step 4 to determine if capacity in the design age is equal to or greater than the average annual snow transport. If capacity is found to be greater than transport, the length of the downwind drift and the required setback will be reduced to some fraction of the maximum $35H_{req}$ as explained in Step 9 below.

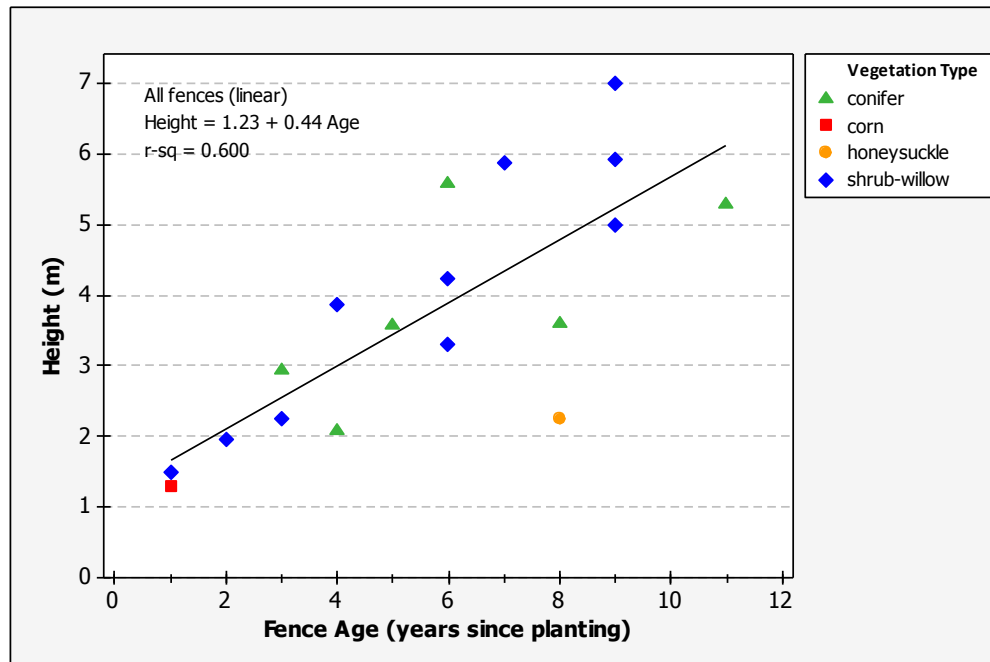


Figure 6 - Fence age versus height (H) of 18 living snow fences of various species in New York State
Diagram by Heavey (2013)

Step 9: Calculate Setback Distance

Setback is the distance from the edge of the roadway to the living snow fence. The estimated length of the downwind drift is the primary determinate of appropriate setback distance. Setback must be large enough to accommodate the entire downwind drift, but not excessively large, as this can cause blowing snow problems between the fence and the road, and also inhibit snow fences in areas where right of way planting space is limited. The simplest method for calculating setback for living snow fences (without modeling different design ages) is to use following equation from Tabler (2003):

$$D = (\sin \alpha)(35H_{req})$$

Where :

D is the setback distance in meters

α is the acute angle of the wind to the road from Step 1

H_{req} is the required height of the fence from step 5



Note that the output for **D** in this equation is based on the minimum required height of the fence (**H_{req}**), not the actual height. **D** is therefore an estimate of the maximum drift length on a fence of the required height, based the snow transport quantity (**Q**). The length of the downwind drift in this case would be approximately 35 times the required height of the fence, or **35H_{req}**, slightly modified by the acute angle of the wind (**α**) in some cases. This represents a conservatively large estimate of the required setback, allowing sufficient space for a full capacity drift of the maximum length to form on a fence of the minimum height. If the species of trees or shrubs that are planted have a mature height that is greater than **H_{req}**, the length of the downwind drift will be reduced to some fraction of **D** as a result of the excess height and storage capacity (see Figure 7 and Figure 8).

A more precise setback distance can be calculated by modeling the length of the downwind drift over time, and deciding the best setback option in the context of site conditions, available right of way planting space, and the long term snow and ice management goals of the site. Downwind drift length and the required setback of living snow fences change over time based on the interplay of height, porosity, and the resulting storage capacity (**Q_c**) relative to snow transport (**Q**). This dynamic is illustrated in Figure 7 and Figure 8, and can be modeled using the following equation from Tabler (2003):

$$L = \{[10.5 + 6.6(A/A_e) + 17.2(A/A_e)^2]/34.3\}(12 + 49P + 7P^2 - 37P^3)(H_{req})$$

- Where:
- L** is the length of the downwind drift in meters at design age (**a**) from Step 6
- (A/A_e)** is equivalent to transport/capacity (**Q/Q_c**) from Steps 4 and 8
- P** is porosity at design age (**a**) from Step 6
- (H_{req})** is the required height of the fence from Step 5

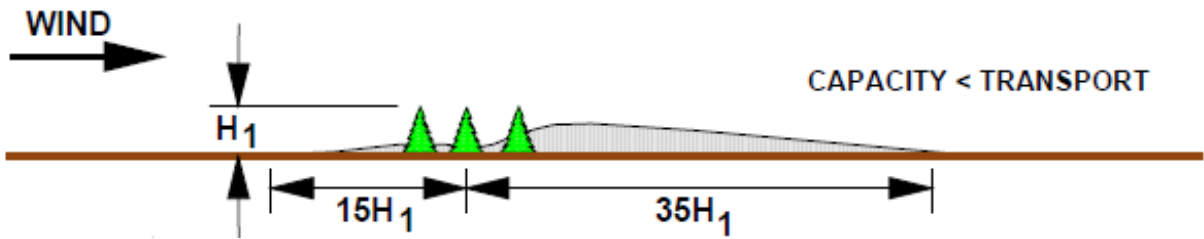


Figure 7 - When fence capacity (**Q_c**) is less than or equal to snow transport (**Q**), the downwind drift length extends to the maximum distance of **35H**, or thirty five times the height of the fence. Diagram from (Tabler, 2003).



Living Snow Fences

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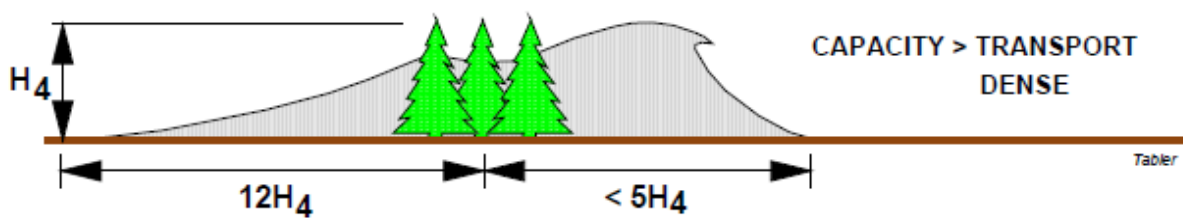


Figure 8 - When fence height (H) is greater than H_{req} , fence capacity (Q_c) becomes greater than snow transport (Q), the downwind drift length (L) is reduced, and the setback distance can be less than $35H$. Diagram from (Tabler, 2003).

Changes in drift shape and length in response to fence height and porosity are based on the aerodynamics of suspended snow particles encountering a porous barrier (i.e. snow fence). Drift formation occurs in distinct stages, illustrated in Figure 9 from Tabler (2003). The maximum drift length occurs in the final stage of drift formation when the fence is at full capacity (equilibrium). If capacity exceeds transport ($Q_c > Q$), living snow fences will not fill to maximum capacity over the drift accumulation season, and the drift will terminate prior to the maximum length of 35 times the height of the fence (Tabler, 2003). The larger the storage capacity relative to transport, the shorter drift length will be. More information on this topic is available in Tabler (2003) and Heavey (2013), referenced at the end of this fact sheet and available for download at www.esf.edu/willow.

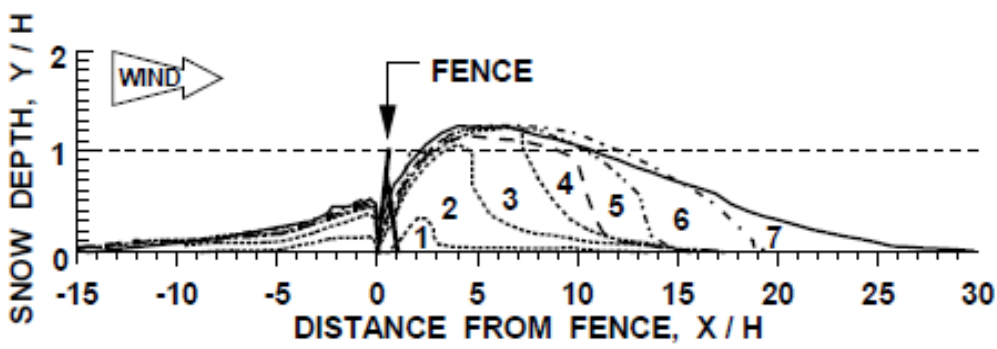


Figure 9 – Stages of drift formation observed around a 50 percent porous structural snow fence (the same principles of drift formation also apply to living snow fences)
Source: Tabler (2003)

It is recommended that drift length be modeled at several different design ages (**a**) by repeating Steps 6 through 9, and the design team then chose a setback that is most appropriate in the context of estimated fence performance over time, the available right of way space or other planting limitations of the site, and the long term snow and ice management goals for the specific location that the fence is to be installed.



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Available right of way space is often an important consideration when selecting a setback distance, as many locations across the state with blowing snow problems have limited right of way space available for planting, and acquiring additional land may not be feasible. Estimating drift length at different design ages can inform the design team whether or not a living snow fence is feasible on sites with limited right of way space. A temporary structural snow fence can also be used in conjunction with a living snow fence and reduced setback, to prevent snow encroaching on the road while the living fence grows to a height in which the downwind drift length is reduced.

Living Snow Fence Design Example

The following design example uses the steps outlined in this fact sheet, applied to a case-study of a real shrub-willow living snow fence that was installed through the cooperative efforts of SUNY ESF and NYSDOT. The variables used in this example represent the real values collected from the site. The fence was installed in NYSDOT Region 3, town of Preble, NY, in the southbound right of way of Interstate-81 at approximate reference marker 81I 3202 3094. The fence was installed in 2004, and has grown and functioned as expected since installation, preventing blowing and drifting snow from encroaching on the roadway in an area that was previously prone to frequent blowing snow problems.

Step 1: Determine Fence Orientation

Based on reports from snow and ice maintenance staff, and observations of drifts made during the site assessment phase, the snow fence design team determines the wind-angle relative to the road to be approximately 90° ($\alpha = 90$), indicating the fence should be oriented parallel to the roadway (Figure 10).

Step 2: Estimate the snowfall water equivalent (S_{we})

Using the site elevation of 364 m and latitude of 42° (measured using mapping software), the team estimates the snowfall water equivalent over the accumulation season (S_{we}) at the site:

$$S_{we} = (-695.4 + 0.076 * \text{Elev} + 17.108 * \text{Lat}) (0.0254) (0.10)$$

$$S_{we} = (-695.4 + 0.076 * 364 + 17.108 * 42) (0.0254) (0.10)$$

$$S_{we} = 0.129$$

Step 3: Measure Fetch Distance (F)

The team measures the Fetch using mapping software, and determines it to be 480 m (Figure 10).

Step 4: Calculate Snow Transport (Q)

The team uses the S_{we} and F values from Steps 2 and 3 to calculate the snow transport in tons per meter (t/m) at the site:

$$Q = (1500) (0.17) (S_{we}) (1 - 0.14^{F/3000})$$

$$Q = (1500) (0.17) (0.129) (1 - 0.14^{480/3000})$$

$$Q = 9 \text{ t/m}$$

Living Snow Fences

Fact Sheet Series - Fact Sheet #3
Living Snow Fence Design

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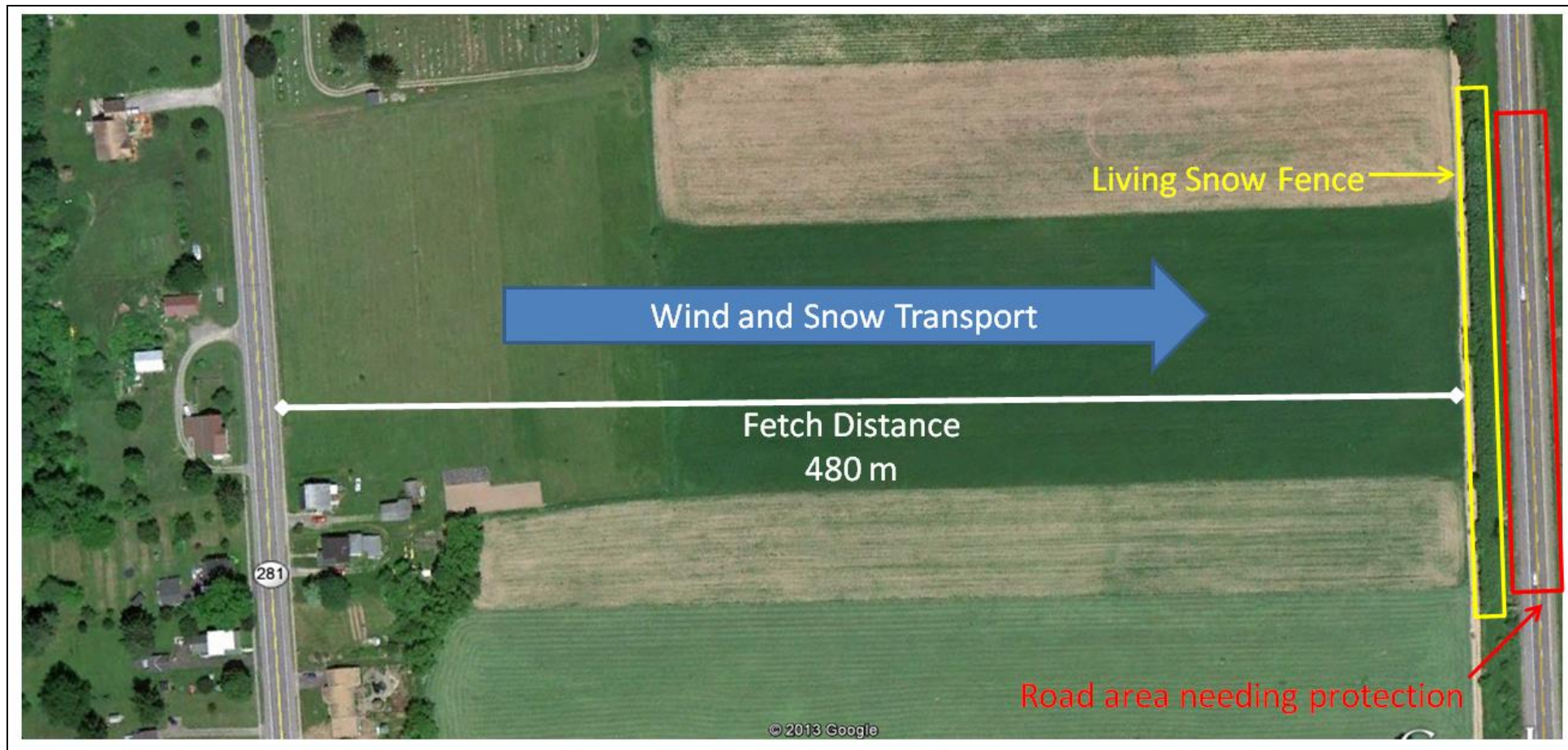


Figure 10 - Aerial photo of living snow fence site along Interstate-81 S in Preble, NY showing wind direction, fence orientation, and fetch distance. Diagram by SUNY ESF.



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Step 5: Calculate Required Height (H_{req})

The team uses the **Q** value from Step 4 to determine the required height (**H_{req}**) of the fence which is calculated at 1.0 m, indicating that the chosen species must grow to at least 1 m in height in a reasonable time frame.

$$H_{req} = (Q/8.5)^{0.455}$$

$$H_{req} = (9/8.5)^{0.455}$$

$$H_{req} = 1.0 \text{ m}$$

Step 6: Select a Species and design age (a)

The team decides to use shrub-willows for the snow fence. The team selects a design age of 7 years, when the fence is expected to be functional and nearing its full mature height. This is considered a good temporal starting point for analysis because the fence is likely to achieve partial or full functionality several years prior, but also live and function as a snow fence for at least another 10 - 15 years after this point with only minor changes in Height and Porosity.

Step 7: Estimate Optical Porosity (P) in the design age

The team chooses two fast-growing species of shrub-willow and decides to inter-plant them in two offset rows at the recommended spacing of 2 ft between plants, and 2.5 ft between rows. The team estimates that, with this planting pattern, porosity will be 40 percent (0.40) in design age of 7 years.

Step 8: Estimate Height (H) and Capacity (Q_c) in the design age

The team estimates that fence height in the chosen design age will be 6 m, and calculates the snow storage capacity using this height value and the Porosity (**P**) value from Step 7:

$$Q_c = (3 + 4P + 44P^2 - 60P^3) H^{2.2}$$

$$Q_c = [3 + 4(0.40) + 44(0.40)^2 - 60(0.40)^3] 6^{2.2}$$

$$Q_c = 402 \text{ t/m}$$

Comparing this **Q_c** output to the **Q** value from step 4, capacity is much greater than transport (**Q_c = 44Q**). This indicates that the drift length and appropriate setback distance will be reduced due to the large amount of excess storage capacity of the fence. Even if snow transport in a given winter is double the average (**2Q**), which is a 1 in 1000 winters occurrence (Tabler, 2003), the fence still has 22 times the storage capacity that is necessary, and the majority of snow transport will be stored upwind and in close proximity downwind of the fence.

Step 9: Calculate Setback Distance

Using the porosity (**P**) value from Step 7, the required height (**H_{req}**) from Step 5, and **Q/Q_c** values from Steps 4 and 8, the team calculates the downwind drift length (**L**) in design age seven:

$$L = \{[10.5 + 6.6(Q/Q_c) + 17.2(Q/Q_c)^2]/34.3\}(12 + 49P + 7P^2 - 37P^3)(H_{req})$$

$$L = \{[10.5 + 6.6(9/402) + 17.2(9/402)^2]/34.3\}(12 + 49(0.40) + 7(0.40)^2 - 37(0.40)^3)(1.0)$$

$$L = 9.4 \text{ m}$$



The output of this equation indicates that the fence is expected to produce a drift length of 9.4 m in average winter at age seven. Even if the snow totals are double the average (2Q) in the snow season of age seven, the fence will still have large amounts of excess capacity, and the drift length will likely not be significantly longer than expected in the average winter. It is assumed that the fence will achieve some functionality prior to age seven, and also live at least 10 - 15 years beyond age seven, so the design team repeats steps 6 through 9 using design ages: 4, 10, and 15. The drift length output changes slightly with each design age as expected, and the team selects the final design age and corresponding setback distance that is most appropriate based on the estimates of drift length, existing and available right of way space for planting, and the long term snow and ice management goals for the site.

Note: The actual fence that this example is based on was planted on the far edge of the right of way boundary, at a setback distance of approximately 9.5 meters. The fence achieved functionality in the third winter after planting, and has since provided adequate protection of the roadway from blowing snow without drift encroachment onto the road.

Sources

Heavey, J.P. 2013. *Structure and function of living snow fences in New York State*. State University of New York -College of Environmental Science and Forestry. Syracuse, NY.

Tabler, R.D. 2000. *Climatological analysis for snow mitigation in New York State*. Tabler and Associates. Niwot, CO.

Tabler, R.D. 2003. *Controlling blowing and drifting snow with snow fences and road design*. Tabler and Associates. Niwot, CO.

Additional Resources

The New York State Department of Transportation (NYSDOT) and the State University of New York College of Environmental Science and Forestry (SUNY ESF) provide additional information relevant to the design of living snow fences on their web sites which can be accessed at the following web addresses:

www.nysdot.gov

www.esf.edu/willow

Materials available online include: additional fact sheets in this series, a species matrix for living snow fences, a cost-benefit model for living snow fences, and other informational and instructional materials.

Fact Sheet prepared for NYSDOT by Justin P. Heavey and Timothy A. Volk, SUNY-ESF.

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