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Design of Living Barriers to Reduce the Impacts of Snowdrifts on Illinois Freeways

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16. Abstract
Blowing snow accounts for a large part of Illinois Department of Transportation's total winter maintenance expenditures. This project aims to develop recommendations on the design and placement of living snow fences (LSFs) to minimize snowdrift on Illinois highways. The research team examined historical IDOT data for resource expenditures, conducted a literature review and survey of northern agencies, developed and validated a numerical model, field tested selected LSFs, and used a model to assist LSF design. Field testing revealed that the proper snow fence setback distance should consider the local prevailing winter weather conditions, and snow fences within the right-of-way could still be beneficial to agencies. A series of numerical simulations of flow around porous fences were performed using Flow-3D, a computational fluid dynamics software. The results of the simulations of the validated model were employed to develop design guidelines for siting LSFs on flat terrain and for those with mild slopes (< 15° from horizontal). Guidance is provided for determining fence setback, wind characteristics, fence orientation, as well as fence height and porosity. Fences comprised of multiple rows are also addressed. For sites with embankments with steeper slopes, guidelines are provided that include a fence at the base and one or more fence on the embankment. The design procedure can use the available right-of-way at a site to determine the appropriate fence characteristics (e.g., height and porosity) to prevent snow deposition on the road. The procedure developed in this work provides an alternative that uses available setback to design the fence. This approach does not consider snow transport over an entire season and may be less effective in years with several large snowfall events, very large single events, or a sequence of small events with little snowmelt in between. However, this procedure is expected to be effective for more frequent snowfall events such as those that occurred over the field-monitoring period. Recommendations were made to facilitate the implementation of research results by IDOT. The recommendations include a proposed process flow for establishing LSFs for Illinois highways, LSF siting and design guidelines (along with a list of suitable plant species for LSFs), as well as other implementation considerations and identified research needs.

Key Words
Living Snow Fence, Snow Fences, Snowdrifts, Snow and Ice Control, Modeling, Computational Fluid Dynamics, Costs, Design, Transportation Operations, Winter Maintenance, Snow Mechanics

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- Dean Mentjes, Federal Highway Administration
- Jim Alwill, Illinois Department of Transportation
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EXECUTIVE SUMMARY

The objective of this project is to develop recommendations on the design and placement of living snow fences (LSFs) to minimize snowdrift on Illinois highways. More effective and efficient snow and ice control operations on Illinois highways could result in significant economic, environmental, and social benefits. Thus, it is desirable to improve the use of living barriers as a passive yet sustainable snow and ice control measure for Illinois freeways. A LSF is an emerging alternative to structural snow fences and provides a longer-lasting, low-maintenance, and cost-effective solution to snow drifting, reducing the need for excessive use of plowing, chemicals, or road closure and improving winter road safety. Prior to this study, research was lacking in the site-specific design of LSFs to reduce the impacts of snowdrifts, and current design protocols have been based on semi-empirical assumptions and were unable to guide the proper siting and design of LSFs.

This project was conducted using the following approach. First, the research team examined Illinois Department of Transportation's (IDOT) historical snow-event reports to investigate the extent of resource expenditures of personnel, equipment, and material dedicated to keeping roads open during snowdrifts. Second, the research team conducted a review of barrier treatments and policies by other northern states, including the history, design protocols, siting policies, benefits, challenges, and numerical modeling of snow fences. Third, the research team developed a computational fluid dynamics (CFD) model to numerically simulate snow drifting around LSFs. This was followed by field testing of selected LSFs in the Illinois highway system as well as model validation and calibration. The established model was employed to assist in the siting and design of LSFs and the development of recommendations.

This project reviewed both the literature and survey responses from practitioners in northern states. Recently, more and more departments of transportation (DOTs) recognize the benefits of snow fences and are enrolling or planning to implement snow fence programs, especially LSFs. The survey results show that almost all responding agencies have launched snow fence programs in their districts, with various design and siting protocols according to specific conditions. The factors that affect effectiveness and efficiency were investigated to show the design policies for snow fences. Height, porosity, and length of a snow fence are the main design parameters, while the bottom gap and wind direction should also be considered. The siting location is another important consideration to ensure that the snow fence prevents snowdrifts from reaching the roadway. The same design and siting principles developed for structural snow fences also apply for LSFs; some modifications, however, are necessary because the height, porosity, and snowdrift length of LSFs change over time as the plants grow. If designed and sited properly, snow fences can improve road safety and provide other benefits. LSFs are preferred by both DOTs and farmers because they are more cost-effective and beneficial to the environment and landowners. However, some challenges exist when installing snow fences on private land in areas with a narrow right-of-way (ROW). The greatest challenge facing snow fences is the difficulty in obtaining agreements with landowners to establish fences on productive land. Some DOTs have found success establishing specific programs to compensate farmers.

This work reviewed IDOT's data on snow and ice removal costs (district and statewide, especially the 2017–18 and 2018–19 winter seasons) to determine the extent of resource expenditures dedicated to keeping roads open and to dealing with blowing snow in Illinois. Although the winter weather severity is the main influential factor and varies from year to year, the winter snow and ice removal labor, equipment, and material expenditures have increased in general over the 2015–16 to 2018–19 winter seasons. Among all nine IDOT districts, district 1 had the highest winter operation expenditures ($17,251,00 to $29,805,000), followed by districts 2, 3, 4, 6, 5, 8, 7, and 9 ($6,403,000 to $12,368,000). IDOT has started to collect blowing snow removal expenditure data separately since the 2016–17 season. Although not all team sections responded to the survey of blowing snow segment lane miles, the data from those that responded show that districts 2, 3, 4, and 5 have higher percentages (30–50%) of blowing snow segments than other districts. This matches the data for total winter snow and ice removal cost, indicating blowing snow costs account for a large part of the total winter maintenance expenditure. This was confirmed by the blowing snow removal cost data.

This work conducted field testing of seven selected LSFs in the state of Illinois highway system to provide data for calibrating the numerical model and to evaluate the effectiveness of LSFs. The activities included site selection, site setup, site monitoring, data collection, and analysis. For each site, the snow depths were measured to catch the snow deposition pattern and determine the potential of LSF to capture snow. The test sites were monitored over two winter seasons and several snow events were recorded each winter. Volumes of snow deposited at snow fence sites were calculated for comparison with their controls. From the data collected, snow deposition was generally higher immediately behind the snow fence barrier and decreased gradually with the increase in distance from the snow fence toward the roadway. The snow volume results showed higher snow deposition volumes of nearly all fenced sites than their controls. Despite not having a long setback distance from the roadway, as suggested by past studies, the tested LSFs in Illinois that were within a ROW were effective in trapping blowing snow during the milder winters experienced during the study. No evidence showed that high-volume snow was deposited on the roadway at those sites. This finding indicates that the proper snow fence setback distance should consider the local prevailing winter weather conditions, and snow fences within ROW can still be beneficial to agencies.

A series of numerical simulations of flow around porous fences were performed using the CFD software Flow-3D. The modeling approach was validated using laboratory data collected in a wind tunnel for flow around a fence with nonuniform porosity. Following validation, the numerical approach was used to test a model for fence porosity and investigate the effect of row spacing for fences comprised of two rows of vegetation. The simulations focused on a range of average wind speeds and fence porosity over flat terrain, and the results of these simulations were used to estimate the region of snow deposition using a threshold shear velocity. For sites where the terrain cannot be considered flat, simulations were performed for an embankment with different fence configurations.

The CFD simulations provide an estimate of the length of the region where snow deposition is expected as a function of fence characteristics. Subsequently, the results of the simulations are employed to develop design guidelines for LSFs. These guidelines are presented for siting LSFs on flat terrain and those with mild slopes (< 15° from horizontal). Guidance is provided for determining fence setback, wind characteristics, fence orientation, as well as fence height and porosity. Fences comprised of multiple rows, such as standing rows of corn, are also addressed. For sites with embankments with steeper slopes, guidelines are provided that include a fence at the base and one or more fences on the embankment. The design procedure uses the available ROW at a site to determine the appropriate fence characteristics (e.g., height and porosity) to prevent snow deposition on the road. This approach of using the available length for deposition to determine fence characteristics differs from prior snow fence design procedures. Past procedures estimate the total snow transport during a winter season and determine the fence characteristics and setback required to store snow away from the road for an entire winter season. While those designs have been effective, the resulting setback may be difficult to achieve at sites with limited ROW. The procedure developed in this work (embodied in a design spreadsheet tool) provides an alternative that uses available setback to design the fence. This approach does not consider the snow transport over an entire season and may be less effective in years with several large snowfall events, very large single events, or a sequence of small events with little snowmelt in between. However, this procedure is expected to be effective for the more frequent snowfall events such as those that occurred over the field-monitoring period.

This report presents the main conclusions of this project, followed by a list of recommendations to facilitate the implementation of the results by IDOT. The recommendations include a proposed process flow for establishing LSFs for Illinois highways, siting and design guidelines of LSFs (along with a list of suitable plant species for LSFs), and other implementation considerations of LSFs. This project also identified a few research needs, including:

(1) Strategies to enable partnerships with adjacent landowners to expand the size of LSFs.

(2) Alternative use of ROW and the associated cost-benefit analysis.

(3) Better quantification of the costs and benefits of implementing LSFs at roadway sites.

(4) How the characteristics of snow, different modes of snow transport, and field tillage operations on lands adjacent to ROW affect snow deposition and the effectiveness of LSFs.

(5) Economical means for implementing various LSFs.

(6) Upon examining how different plant species react to coppicing, investigate methods and best species for coppicing procedures to maximize effectiveness of LSFs.

(7) Environmental factors that affect the performance and longevity of various LSFs.

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CHAPTER 1: INTRODUCTION

BACKGROUND

For certain highway segments in northern climates, snow drifting can create hazardous driving conditions or necessitate nearly continuous plowing, excessive use of chemicals, or road closure (Tabler, 2003). Structural (wooden, plastic, or metal) snow fences have been designed to disrupt wind patterns, decelerate the wind-blown snow, and constrain it to a designated area other than a pavement surface (Figure 1). If properly sited and designed, snow fences are proven to reduce the negative impacts of blowing and drifting snow on roadway safety and mobility (Kumar, 2015; Tabler & Meena, 2006), while providing low-cost snow storage. For instance, snow fences have been reported to significantly reduce accidents during blowing snow conditions and reduce snow and ice control costs (Tabler & Furnish, 1982). Areas protected by snow fences can be 10°F warmer than adjacent unprotected road pavements (Tabler, 2004).

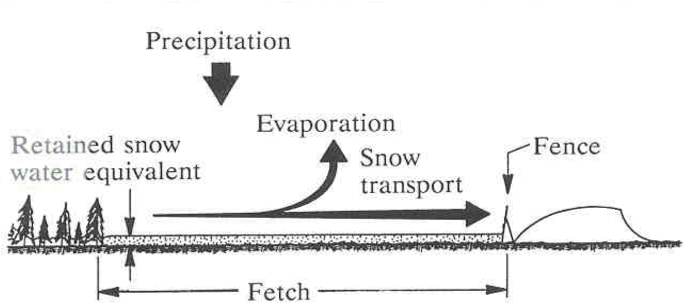


Figure 1. Diagram. The fetch concept used to estimate snow transport.

Source: Tabler, 1991

An alternative to a structural snow fence is a living snow fence (LSF) such as strategically planted trees, shrubs, and prairie grasses as windbreaks (Figure 2), which provides a longer-lasting, low-maintenance, and cost-effective solution to snow drifting (Heavey, 2013; Nixon et al., 2006; Tabler, 2003; Daigneault & Betters, 2000; USDA, 1994). In addition to high snow-storage capacity, LSFs feature additional benefits in providing carbon sequestration, enhancing wildlife habitat, improving erosion control and water quality, as well as reducing flooding.

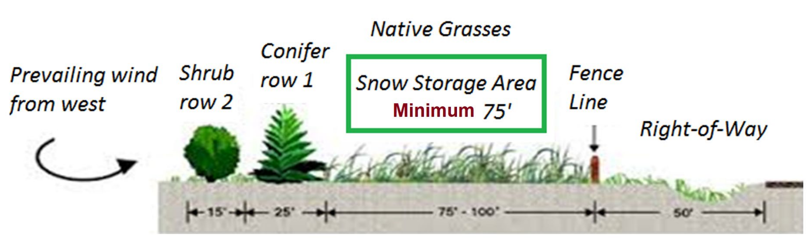


Figure 2. Diagram. Schematic design of a living snow fence.

Source: Wyatt et al., 2012b

PROBLEM STATEMENT AND PROJECT OBJECTIVE

Despite the extensive studies on structural snow fences, research is lacking in the site-specific design of LSFs to reduce the impacts of snowdrifts. Existing design protocols are based on semi-empirical assumptions about snow transport and deposition around structural barriers, which fail to represent the diverse scenarios around LSFs (Nixon et al., 2006) or guide proper siting and design. More effective and efficient snow and ice control operations on Illinois highways could result in significant economic, environmental, and social benefits. Thus, it is desirable to improve the use of living barriers as a passive yet sustainable snow/ice control measure for Illinois freeways. Fluid flow, such as wind around a living fence, can be studied in the field, laboratory, or numerically. Field and laboratory approaches may become impractical for design studies because of the high costs and efforts required to reproduce the wide range of possible conditions. This is the case with LSFs, where each fence may be comprised of different types of plant species and is placed in a unique topography, prevailing wind conditions, and roadway geometry. An alternative to direct measurements in the field or laboratory is to approach the problem numerically.

In this context, the objective of this project was to develop recommendations on the design and placement of living snow fences to minimize snowdrift. The following approach was taken. First, we conducted a review of the Illinois Department of Transportation's (IDOT) 2013–2014 snow-event reports to determine the extent of resource expenditures of personnel, equipment, and material dedicated to keeping roads open. Second, we conducted a review of other northern DOTs' barrier treatments and policies as well as their effectiveness. Third, we developed a computational fluid dynamics (CFD) model to incorporate aerodynamic transient snowdrift development and computer-aided design and drafting drawings, enabling site-specific analysis. Fourth, we conducted field testing at locations where snow barriers are used to control snow accumulations and then use the field data for model verification and calibration. Once the model was finalized, we employed it to assess the effect of freeway interchanges and roadway sections (e.g., upwind ditch depth and other ground modification) on the performance of snow storage and identify critical design parameters affecting the performance of LSFs.

Research Approach

The research approach is broken into seven tasks, each of which is detailed in this section. Note that the actual execution of the research project slightly deviated from the plan detailed in the next sections. This deviation was typically the outcome of consultation with the Technical Review Panel (TRP) to best address IDOT priorities within practical constraints (e.g., warm winter seasons over the project duration and lack of access to certain types of historical data).

Task 1: Determining Resource Expenditures

The research team conducted a review of IDOT's snow-event reports from the past six years to determine the extent of resource expenditures dedicated to keeping roads open. The resources considered are mainly personnel, equipment, and materials. With the snow and ice removal cost reports obtained from IDOT, the expenditures were determined by each district and then summarized for the entire state. These might include contracted services. The personnel expenditure included the regular labor and overtime winter labor costs to clear roads and remove snow. It also included costs involving coordinating within various levels of managements; determining personnel, equipment, and material needs; assigning personnel, equipment, and material; establishing plow and spreader rates; road patrol and road/weather condition reporting; emergency operations; and personnel training. The equipment expenditure considered all snow-removal equipment, such as trucks, plows, graders, spreaders, loaders, cleaners, snowblowers, liquid dispensing and blending units, etc. The costs included new equipment purchase, equipment maintenance, parts replacement, fuel and gas, etc. The use of advanced systems/software, e.g., a decision-supporting system, plow-routing software, and automatic vehicle location, was also included. The materials expenditure covered the storage, transport, and costs of salt, sand, and alternative chemicals. This was stored in a digitalized database format and summarized. The expenditure rate per lane mile, per unit snowfall, can be determined to compare the costs across districts and from year to year.

Task 2: Review of Northern DOT Practices

We conducted a review of barrier treatments and policies implemented by other northern departments of transportations as well as their effectiveness. We conducted a review of several databases to gather relevant information, including: Transportation Research Information Service, Google Scholar, ISI Web of Science, Washington State University Library, etc. In addition, we surveyed all snow and ice states (e.g., Iowa, Colorado, New York, Minnesota, Wyoming) to gather information about their use of structural and living snow fences for snowdrift mitigation, siting policies/considerations, design protocols, modeling approaches or tools, initial and maintenance costs, success stories, lessons learned, etc. The review focused on capturing the experience and insights of the winter maintenance community/practitioners and helped shape the scope of modeling and field investigation tasks. All 29 Clear Roads member states were invited to take the survey, along with other states, provinces, international highway agencies, and agencies.

Task 3: Modeling Snow Drifting around Living Snow Fences

We developed a state-of-the-art computational fluid dynamics (CFD) model, instead of a finite element (FE) model, for more accurate and reliable simulation of snow drifting around LSFs. The CFD model aimed to incorporate computer-aided design and drafting (CADD) drawings, enabling site-specific analysis (with or without LSF). The flexibility of CFD makes it well suited for this study. CFD is increasingly applied to environmental flows with recent studies on snowdrift modeling around a building (Tominaga et al., 2011) and across an ice cap (Sauter et al., 2013). This project extended CFD modeling to include a porous, living fence.

Numerical modeling of snowdrifts requires mathematical models describing the wind and the mechanisms of snow erosion and deposition. Scale—both spatial and temporal—is an important consideration for these models. In snowdrift applications, models may be continuous—simulating large areas over an entire snow season—or event based—simulating a single snow event. Because of the large scales considered, continuous models rely on simplifying assumptions and are often parameterized from field measurements (e.g., Walter et al., 2004; Durand et al., 2004; Chen et al., 2009; Grover et al., 2012); whereas, event-based models seek to represent the underlying physics of the problem and limit parameterization (Uematsu et al., 1991; Xu et al., 2014). Continuous models may not be sufficient for the problem of flow around an LSF, where small-scale topographic features likely significantly influence snowdrift. This difference is highlighted in Chen et al. (2009) where the introduction of a second fence to a continuous model (SnowMan^{TM}) results in the addition of a new equation to represent the effects of the second fence on snowdrift. In an event-based model, a second fence is part of the geometry, and the flow field around the fences and resulting deposition is calculated without altering the fundamental physical equations. In this approach, the influence of the second fence as well as interaction between fences on flow and snow transport and deposition can be investigated.

To capture the effects of topography, including buildings and fences, recent work has employed CFD (e.g., Uematsu et al., 1991; Sundsbø, 1998; Beyers et al., 2004; Tominaga et al., 2011). Numerical modeling with CFD of fluid flow around structures ranging from airfoils to buildings to river channels is well established (Ferziger and Perić, 2002). The challenge when developing a CFD model of LSFs is the representation of snowdrift processes. Two basic approaches for representing snow within a CFD model exist. The Lagrangian, or particle-tracking, approach uses equations describing particle motion to calculate the path of individual snow particles. The primary weakness of this approach is the additional computational effort required to simulate the motion of many individual snow particles. The Eulerian, or multi-phase, approach treats the snow as a second fluid phase. In other words, snow is modeled as a fluid that mixes with the primary fluid—air. The Eulerian approach requires only a single set of additional equations to represent the snow phase. Due in part to this reduced computational effort, most CFD simulations of snowdrift employ the Eulerian approach (e.g., Tominaga et al., 2011; Xu et al., 2014). Within the Eulerian framework, numerous models have been proposed to represent the different modes of snow transport—creep, saltation, and suspension (Bagnold, 1941). These models vary in the treatment of transport dynamics, but all require some parameterization. At present, CFD models of snowdrift around structures reproduce qualitative patterns of erosion and deposition (Tominaga et al., 2011). In general, a lack of sufficient field data has prevented thorough model validation. This study will extend CFD modeling of snowdrift by including model validation with field measurements (Tasks 4 and 5).

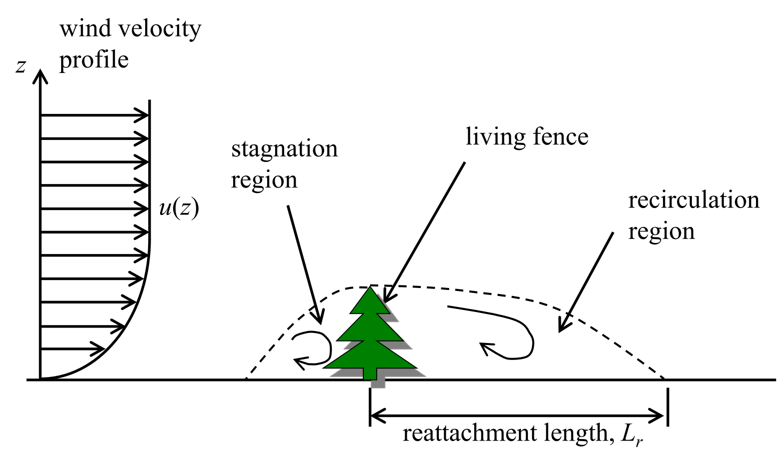


Figure 3. Diagram. Schematic of geometry and flow features for a living snow fence.

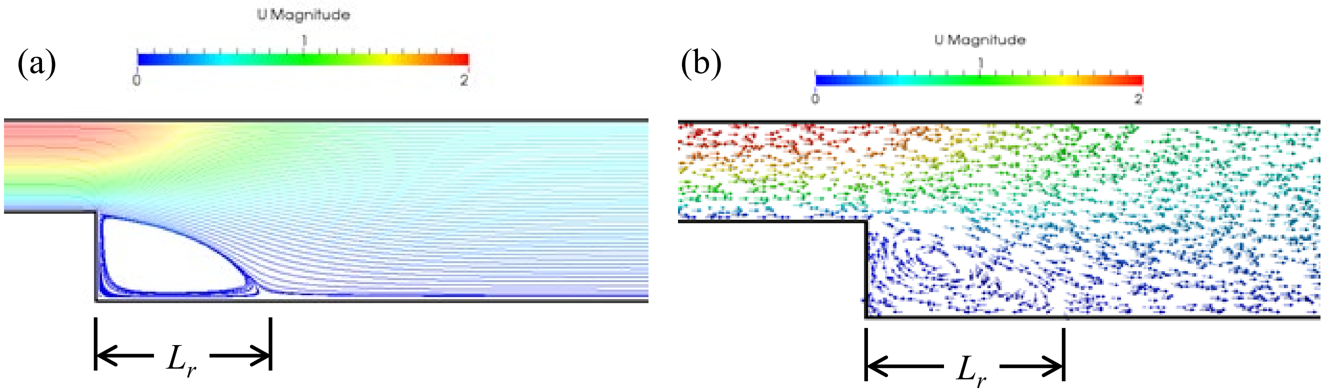


Figure 4. Diagram. (a) Streamlines and (b) velocity vectors in *m/s* from a CFD simulation demonstrating the recirculation region and reattachment length L_r in a pipe with a sudden expansion.

Source: Carrillo et al., 2014

CFD models compute the flow field and associated properties (e.g., snow deposition) using fundamental physical equations; therefore, simulations must be designed to capture the geometric and flow features of the problem. For wind around an LSF, the geometry includes the fence itself and the terrain on which the fence is located (Figure 3). In addition to the LSF geometry, porosity (the ratio of the fence area to its total frontal area) must be specified. The flow features include the approach wind velocity profile and regions of stagnation and recirculation shown in Figure 3. The stagnation region forms due to the approach wind impinging on the fence while the recirculation region is caused by flow separation over the fence. Both regions contain low wind velocity and flow recirculation—features that result in deposition of snow. The location downwind of the fence where the flow reattaches to the ground, called the reattachment length, likely identifies the deposition region. Carrillo et al. (2014) found that the reattachment length obtained from CFD simulations agrees well with laboratory measurements for a sudden expansion in a pipe flow (Figure 4). The extent of the stagnation and recirculation regions is determined by the fence geometry and porosity, approach wind velocity profile, and the terrain. The proposed systemic CFD study will quantify the general effects of each controlling feature as well as develop a general methodology that can be applied to specific sites.

Because of the computational expense of 3D simulations, it is important to identify if the flow can be modeled sufficiently in two dimensions. For example, Carrillo et al. (2014) demonstrate that a 2D model predicts flow reattachment lengths that agree well with laboratory measurements (Figure 4). In Tasks 4 and 5, the numerical techniques will be tested and validated using data measured in the field (Nixon et al., 2006). This work includes selecting the appropriate turbulence model, representing the porosity of the fence, and modeling snow transport and deposition. Once Tasks 1 and 2 are completed, a simulation matrix will be developed to assess the influence of fence geometry and porosity on deposition characteristics. The values selected for the fence geometry and porosity as well as wind velocity will be based on the range of values identified in the previous tasks.

Task 4: Field Testing

The research team conducted field testing of LSFs at select Illinois highway locations in order to verify and calibrate the CFD model developed in Task 3. The field testing consisted of three subtasks: site selection, site monitoring, and field measurements.

Site selection: Seven LSF sites in Illinois were periodically tested in this project because of budget and time constraints. To verify and calibrate the CFD model and subsequently determine the key factors that affect LSF design, these sites represented diverse levels of fence height, width, length, density, location (distances from the roadway), porosity, number of rows, plant species, and relative elevation of snow fence and roadway. The selection of testing sites considered roadway orientation, site weather condition (northern vs. southern Illinois), accessibility to taking field measurements, and representation of LSFs across Illinois. Sections on I-55, I-72, I-74, and I-80 were considered good candidates for field sites. The research team monitored the temperature, snowfall, wind speed, and wind direction of the selected sites. When no significant snow event occurred at specific sites during the studied winter, more than three (e.g., six) field sites were selected to ensure sufficient data were obtained in the experiment. We provided candidate sites and coordinated with IDOT to determine the testing sites and make field trips to investigate possible sites based on TRP suggestions. Once the sites were selected, we documented the experiment factorial and surveyed the selected sites and their controls to get the bare ground profile of each site.

Site monitoring: For the selected sites, we set up the necessary equipment, including rods (sticks) at upwind and downwind locations for measuring snow depth. In coordination with IDOT, we closely monitored and recorded the weather and road conditions of these sites. When a snow event occurred, the snowfall, storm duration, temperature, wind speed, and direction were recorded.

Field measurements: Before and after the snow event, we visited the field sites to take the measurements. The key measurements included snow deposition/acclimated snow thickness and area/location affected by snowdrift. The volume of trapped snow of the LSF was calculated using the measuring stick data. This data was useful in determining the ability of snow fences to prevent snow accumulation for each snow event.

Task 5: Model Verification and Calibration

This task entailed the verification and calibration of the CFD model, i.e., ensure that the models can replicate snow deposition profiles observed in the field. Using the field site geometrics data (including bare ground profile and ambient snow cover) and snow-event weather condition recorded as inputs, the CFD model was run to predict the snow deposition pattern (thickness, area, and volume). These model output data was then compared against the field-measured data. In coordination with the TRP, we determined the reasonable tolerance criterion for each predicted data item. Based on the comparison results, the parameters of the CFD model(s) such as those related to assumptions, quantifying characteristics of LSF, and snow transport/deposition dynamics were adjusted until the predetermined criteria are met.

Task 6: Using the Model to Aid Design

Once the model was verified and calibrated, we used it to assess the snow storage performance of a few selected Illinois freeway interchanges and roadway sections, with a focus on IDOT freeway segments that are historically prone to snow drifting. We also assessed how modifications to ditch depth in relation to pavement elevation may improve the snow storage performance and help mitigate snowdrift. This task also involved assessment of the post-construction efficiency of select IDOT LSFs in mitigating snowdrifts by quantifying the spatial distribution of snow accumulation at the fence sites. Using the model to simulate representative IDOT scenarios, we identified critical design parameters that affect snow accumulation such as wind direction and velocity as well as configuration and plant species of LSF.

Like a structural barrier, LSF dissipates the energy from wind gusts to minimize the impacts of snowdrifts. A second component to snow drifting is the blockage or passing of the blowing snow's energy. The best practice is to have adequate storage for the snow upwind of the highway or adequate passage of the snow to not block the opposite side. Cut and fill sections of the roadway in relation to pavement elevation and ditch depth and storage is critical in highway clearing during a snowstorm event. The key to success is to conduct the design (and construction activities) based on careful examination of the existing site conditions and constraints (e.g., prevailing wind speed and direction, target storage capacity, and available land for use in the right-of-way). Figure 5 shows an example ground profile required to generate the snowdrift profile in the region of interest.

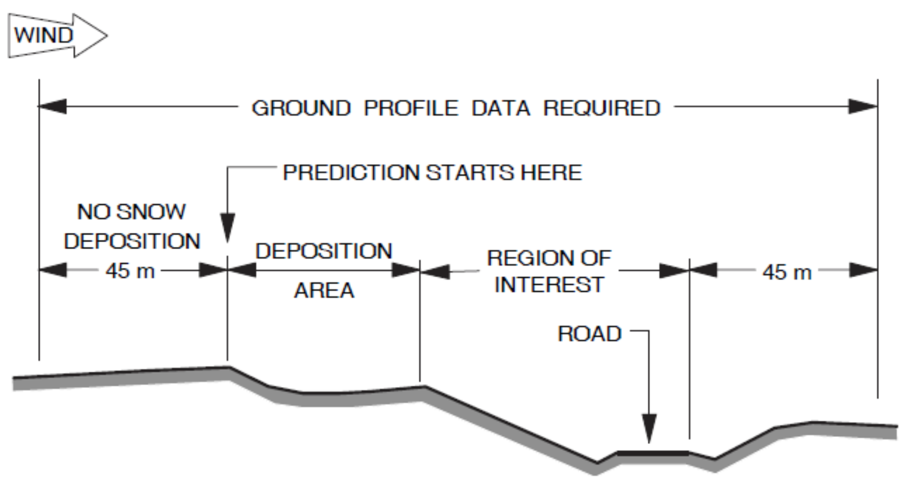


Figure 5. Diagram. Example ground profile required to generate the snowdrift profile in the region of interest.

Source: Chen et al., 2009

Snow fences are a well-established technology typically designed to capture wind-blown snow before it accumulates on a roadway (Tabler, 2003). The general steps for designing a structural snow fence include analyzing the snowdrift problem; defining the area that needs fence protection; determining why the problem exists as well as the wind direction; estimating the snow transport; determining the fence height and the number of rows required; and determining fence placement, layout procedure, and fence orientation. A taller single-row fence is always preferable to multiple rows of shorter fences (Tabler, 1991). The taller fence not only traps more snow, but also more effectively improves driver visibility, costs less, and requires less land. The same principles may hold true for the LSF design configurations.

Tabler (1991) has developed a guide for the design of structural snow fences, including size and placement as a function of average annual snowfall and prevailing wind direction. The design details, however, are not transferrable to LSFs, which feature different snow-storing capacity and aerodynamic characteristics than conventional barriers. The model developed in Task 3 and verified/calibrated in Task 5 will allow the research team (and IDOT designers) to (1) anticipate the specific characteristics of a highway segment's potential drifting areas and to design adequate elevations of the roadway in relation to ditching and snow barrier locations, (2) evaluate use of LSFs in controlling snowdrift at freeway interchanges and gore areas, and (3) select details for LSFs.

The design will examine LSFs on and off the right-of-way and build on existing knowledge about LSFs. For instance, the more open or porous the snow fence, the longer and shallower the drifts (Nixon et al., 2006). The analyses allow the evaluation and visualization of snowdrift development as a function of localized site topography, climatic conditions, and LSF design, which assists the conceptual LSF design process to manage potential snowdrifts at typical IDOT trouble spots. For optimal LSF placement and configuration, the design parameters for exploration will include distance from the roadway, effective length, selection of typical Illinois plant species, number of rows, and spacing in and between rows (Shaw, 1988).

Task 7: Final Report and Recommendations

The team developed recommendations for IDOT to properly site and design LSFs for mitigation of snowdrift on Illinois highways, considering findings from the previous tasks (especially Tasks 1, 2, and 6). Recommendations included guidelines for LSFs pertaining to location, orientation and layout, height, density, and type of living barrier, including standard details. Recommendations were explored for adequate elevations of the roadway in relation to ditching and snow barrier locations. Considerable weight was given to the need to develop recommendations and design protocols that are technically, economically, and politically feasible. In the case of placing LSFs, the recommendations considered the concerns of farmers and other landowners as well as constraints related to use of noninvasive species and potential interference with driver visibility or wildlife. Based on the evaluation completed in Task 6, recommendations were made regarding the placement and design of promising LSFs ready to be adopted by IDOT, which should be considered for further evaluation on highway cut sections (e.g., snowdrift-prone freeway interchanges and gore areas) during the next phase of this project.

Report Organization

This report is organized in seven chapters. Following this introductory chapter, Chapter 2 summarizes the current knowledge and practices of using snow fences to reduce the impacts of snowdrifts on highways, based on the findings of Task 2. Chapter 3 presents the methodology of and findings from

Task 1, pertaining to the resource expenditures by IDOT on snow drifting mitigation. Chapter 4 presents the methodology of and findings from Tasks 3 and 5, pertaining to the development, validation, and calibration of the CFD model of snow drifting around LSFs. Chapter 5 presents the methodology of and findings from Task 4, pertaining to field testing of LSFs in Illinois. Chapter 6 presents the methodology of and findings from Task 6, pertaining to the use of the established CFD model to aid in the design of LSFs. Finally, Chapter 7 presents the conclusions and recommendations based on the research findings. Appendices A–H conclude the report.

CHAPTER 2: SNOW FENCES FOR REDUCING THE IMPACTS OF SNOWDRIFTS ON HIGHWAYS—A RENEWED PERSPECTIVE

In northern climates, snow fences are usually established in and/or beyond a right-of-way to eliminate blowing and drifting snow on roadways and improve road safety. To make snow fences more effective on highways and provide guidelines for the departments of transportation (DOTs) siting them, this work reviews both the literature and survey responses from practitioners in northern states. This review combines information obtained from both resources to detail several aspects of snow fences, including the history, design protocols, siting policies, benefits, challenges, and numerical modeling of snow fences. Particular attention is paid to living snow fences as an emerging alternative to the traditional structural snow fence. The survey results show that almost all responding agencies have launched snow fence programs in their districts, with various design and siting protocols according to specific conditions.

INTRODUCTION

In high-latitude and high-altitude regions, blowing and drifting snow is a crucial factor that influences road safety and maintenance during winter seasons (Raderschall et al., 2008; Grover et al., 2012). The amount of snow that blows onto roads may be more than 100 times that which falls directly onto the road (Tabler, 2003). Blowing snow on highways can cause accidents by inducing poor driver visibility, while the snowdrifts caused by blowing snow can damage the infrastructure in addition to impairing transportation conditions (Tabler, 1991; Raderschall et al., 2008). A solution to eliminate this situation is to encourage snow deposition in a specific location away from the roadway. One practical approach to achieve this goal has been using snow fences (Nixon et al., 2006).

Considering the three basic types of snow movement—creep, saltation, and turbulent diffusion (Mellor, 1965)—snow fences cause blowing snow particles to deposit in a specific location before reaching roadways by reducing the wind speed (Tabler, 1991). Generally, there are two basic types of snow fences—structural snow fences (SSFs) and living snow fences (LSFs). SSFs use wood, metal, plastic, or woven fabrics to restrain the wind and usually are established in vertical slat or horizontal rail structures. LSFs are comprised of rows of trees and shrubs or rows of corn that are left standing over winter that keep snowdrifts off the roadway and provide other benefits (Shaw, 1988; Tabler, 2003). To make LSFs more effective in the field, small-scale modeling of snow fences provides advantages over full-scale field experiments such as having more control over parameters and lower cost. The problem with small-scale models is the validity of results when extrapolated to the field scale (Iversen, 1981). A more practical approach is to develop numerical simulations of the snowdrift, which can facilitate the assessment of the impacts of snow on highways (Beyers & Waechter, 2008).

A literature review was conducted to gather and synthesize information on snow fences. In addition, a survey was conducted that focused on practitioners from northern states that face snow-control issues. The survey responses provide a broader perspective on current use of snow fences, benefits and challenges, design details, modeling approaches, etc. By combining the information obtained from both resources, this review contributes a comprehensive state of knowledge on snow fences.

METHODOLOGY

In order to develop a review of snow barrier treatments and policies implemented by northern DOTs, a methodology incorporating an extensive literature review and survey was utilized. This method includes three components: literature review, preliminary survey, and follow-up survey.

The literature review of snow fences gathered relevant information from several databases, including the Transportation Research Information Service, Google Scholar, ISI Web of Science, and Washington State University Library. This information can be used to determine the development of snow fences, how snow fences work, how design factors influence its effects, and agency experiences with snow fences.

In addition, a preliminary survey was conducted on northern states, along with some provinces in Canada, international highway agencies, and other agencies (e.g., USDA Conservation Reserve Program, Iowa Department of Natural Resources, South Dakota Department of Agriculture, and Kansas Forest Service). The preliminary survey consisted of seven questions and was developed to gather information regarding the use of structural and living snow fences for snowdrift mitigation, siting policies/considerations, design protocols, modeling approaches or tools, initial and maintenance costs, success stories, and lessons learned. The survey responses are expected to provide first-hand experience and insights from the winter maintenance community and practitioners as well as help shape the scope of modeling and field investigation tasks. In the survey, every effort was made to ensure that the survey instrument received a high response rate in a timely manner. As a result, 31 practitioners participated in the preliminary survey, with two from Canada and the rest representing 21 different US states and agencies (Figure 6). In some responses, the answers to some questions were left blank due to a lack of available data or experience from the respondent. Therefore, the summaries in these cases used information provided by fewer than 31 participants. Follow-up phone interviews were conducted as needed to obtain further information or clarification.

HISTORY OF SNOW FENCES

Snow fences were first used to manage snowdrift on railroads in 1852 (Tabler, 2003). Little progress was made in snowdrift control during the following half century, however. This period coincided with developments in mechanical equipment such as trucks, locomotives, and snowplows. Fuel and manpower were relatively inexpensive, providing little incentive to adopt passive snowdrift control measures (Tabler, 2003). Additionally, there was a lack of effective guidelines for siting and designing snow fences. If not placed and designed properly, snow fences can result in more severe blowing and drifting snow on the roadways.

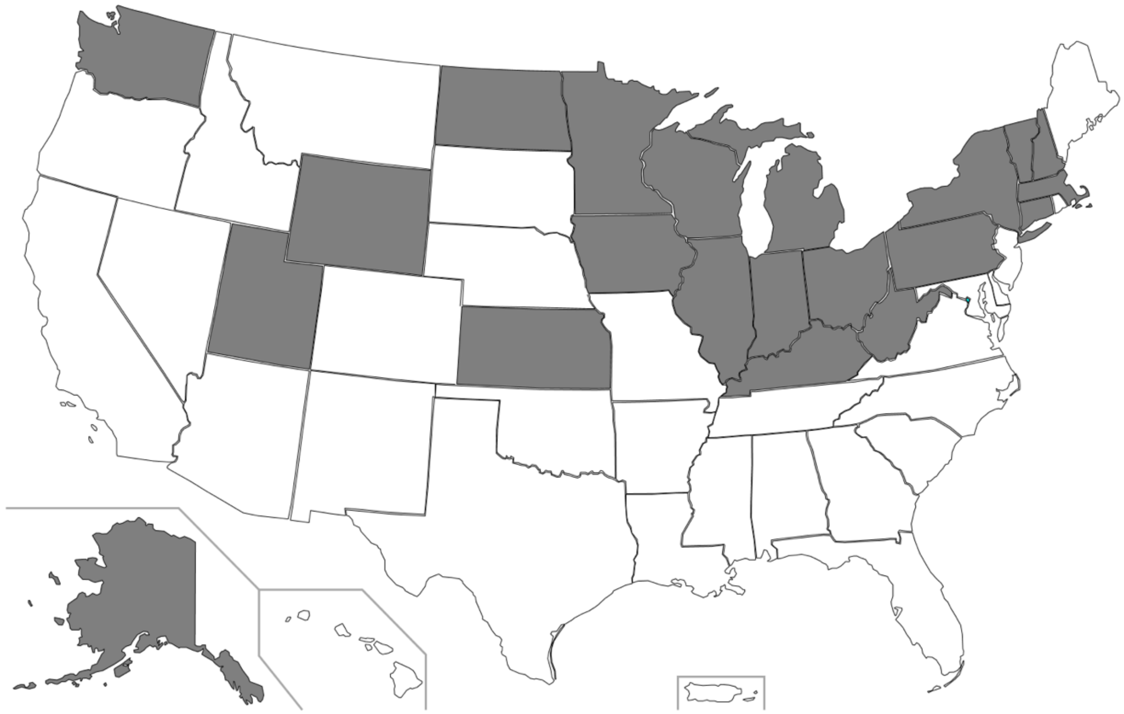


Figure 6. Picture. Map of the United States with the 21 surveyed states highlighted in gray.

In the 1900s, snow fences were readopted as snow barriers to control blowing and drifting snow (Shaw, 1989). DOTs in the United States began widely using snow fences on highways in the 1930s, as automobiles came into general use (Shaw, 1988). Research on snow fences and drift-control methods then grew extensively using both field tests and model approaches. The Wyoming Highway Commission reported 63 miles of fence along Wyoming's highways that were initiated in 1927 and concluded that snow fences were the most economical approach to control drifting snow on highways (Tabler, 2003). The Michigan State Highway Department also began a snow fence program by planting trees after studying drifting snow and control measures in the 1930s. In 1963, Iowa DOT installed shrub-type plants along Iowa's interstate highways and found that the living barriers were cost-effective (Shaw, 1989). In the 1970s, the Wyoming DOT established a new LSF program along a highway subject to severe snowstorms in winter and reported that the snow fences made the road safer and provided additional benefits (Tabler, 1991). In the 1990s, the Minnesota DOT conducted an LSF program and proved that LSFs can also be profitable for the landowner (Streed & Walton, 2001). Testing during the winter seasons from 2001 to 2004, research personnel in Iowa found that rows of standing corn placed at the edge of a field provide comparable snow storage to traditional wooden snow fences (Nixon et al., 2006). A similar conclusion was also observed in the state of New York, where researchers studied the design and siting principles of 18 LSFs planted in recent years and concluded that the setback distance can be much smaller than what is recommended (Heavey & Volk, 2014).

The survey responses of professionals in northern DOTs reveal that almost all have blowing and drifting snow issues on highways in the winter. The severity of the problem increases with increasing latitude. Alaska faces significant challenges to road safety because the entire state is a snow region and drifting snow can occur at any time. Most agencies have established snow fences or have plans to adopt snow fences to control blowing and drifting snow on their highways. Table 1 indicates the number and percentage of the survey respondents who reported the presence of blowing and drifting snow issues and the type of snow fences implemented in their districts. Recently published guides have appeared to assist in implementing snow fences such as the Strategic Highway Research Program Project (Tabler, 1991, 1994) and the National Cooperative Highway Research Program Project (Tabler, 2003).

Table 1. Number and Percentage of States That Faced Snowdrift Issues and Adopted Snow Fences*

Items	Blowing and drifting snow issue	Structural snow fence only	Living snow fence only	Both snow fences
Number of respondents (n)	30	9	8	10
Percentage of respondents (%)	97	29	26	32

*Note: There are cases of multiple respondents from a single state.

DESIGN OF SNOW FENCES

In practice, roads are usually designed to store snow in ditches to prevent snow from accumulating on the road and reduce road safety (Constantinescu et al., 2015; Basnet et al., 2015). However, ideal storage conditions are not always possible when designing roads. If blowing snow reaches a road, accumulation of snow will occur on the highway, eventually forming snowdrifts. Snowdrifts on the road can cause problems such as decreasing road safety, damaging infrastructure, and increasing winter maintenance costs. Road safety impacts by snowdrifts include loss of vehicle control, reductions in visibility and effective road width, and rendering safety barriers ineffective, all of which lead to an increase in car accidents (Tabler, 2003, 2004; Bramb, 2009). Furthermore, snowdrifts can cause major problems for the road (Raderschall et al., 2008). Ice has been reported to form on roads in locations that coincide with blowing and drifting snow (Osborne Jr et al., 2012). When the snow and ice melts, water will infiltrate under the highway pavement (Tabler, 2003). Finally, snow drifting onto highways results in increased winter maintenance costs (Grover et al., 2012; Heavey, 2013; Constantinescu et al., 2015). The equipment and material expenses as well as salaries for the snow-removal crews are the main costs for mechanically removing snow from roadways (Constantinescu et al., 2015). Over 2 billion dollars is spent on snow and ice control operations every year in the United States, and an additional 5 million dollars is needed to repair the infrastructure damaged by snow and ice (Heavey, 2013). Additionally, removing snow on the roadway can lower the usage of the roads while conducting operations.

Snow fences are a cost-effective and efficient technology to prevent blowing and drifting snow on roadways. However, if the snow fence is not properly designed and installed, the roadway may be even more prone to drifting snow (Blanken, 2009). Proper design and maintenance of snow fences can mediate the snowdrift issues described above.

Design of Structural Snow Fences

Structural, or artificial, snow fences can reduce wind velocity and change the wind profile. These changes reduce the ability of wind to transport snow particles, which will allow blowing snow particles to deposit (Tabler, 1991). The deposited snow is then trapped and accumulates behind the snow fence, ideally a sufficient distance away from the roadway (Blanken, 2009). Snow fences must have adequate storage capacity for the specific location to be effective. The storage capacity of a snow fence is often measured by its trapping efficiency, which is defined as the proportion of snow that is trapped by the fence to the whole snow blown across and over the fence (Tabler & Jairell, 1993). It was found that the trapping capacity of a snow fence primarily depends on its length, height, and porosity. Other important factors include the bottom gap, orientation relative to prevailing wind direction, and the developing snowdrift (Tabler & Jairell, 1993; Kumar, 2015).

The length of a snow fence mainly affects the performance of trapping snow by the "end effect," a phenomenon in which snow storage at the ends of the fence is significantly less than that toward the center. Because of the end effect, the fence should extend at least 30 m (100 ft) beyond the end of the protected roadways (Shaw, 1989). Height is another dominate factor affecting the trapping efficiency of the snow fence. The storage capacity was found to be a slightly greater than the square of the fence height. That is, with all other factors kept constant, double the height of the snow fence will result in a more than quadrupling of the snow storage capacity (Tabler, 2003). Taller snow fences not only trap more snow, but also better improve driver visibility. The basic design of structural snow fences according to the survey respondents is either a wooden or plastic 1.22 m (4 ft) high fence attached to steel posts. The trapping capacity of a snow fence is also significantly influenced by the porosity of the fence. Initially, it was believed that leaving 50% of the fence surface area open led to the largest snow storage capacity (Tabler, 2003). A solid snow fence does not collect snow effectively and only traps 35% of the snow that is trapped by a fence with a porosity of 50% (Tabler, 2003). However, a lower porosity snow fence can reduce the length of snow deposited in the leeward of the snow fence, making such fences preferable in areas with narrow right-of-ways (ROW) (Constantinescu et al., 2015). The bottom gap is the space between the ground and the bottom of the snow fence. This gap reduces snow accumulation near the fence, improving trapping efficiency. The optimum bottom gap was found to be equal to 10–15% of the fence height when the fence has a porosity equal to 50% (Tabler, 1991, 2003). As the fence porosity decreases, a larger bottom gap is needed to maintain an effective snow fence (Basnet et al., 2015). To obtain the maximum trapping efficiency, the prevailing wind direction is also used to guide installation. Generally, an orientation perpendicular to the prevailing wind direction is adopted. Additionally, the trapping efficiency of snow fences changes during blown snow events as the fence fills with snow. When the trapping capacity reaches its maximum value, the fence can no longer trap snow. This maximum snowdrift capacity is called the equilibrium drift (Blanken, 2009).

In order to design the snow fence properly, an estimate of the quantity of the blowing snow (snow transport) is required. The distance contributing to the blowing snow, referred to as the fetch, is the distance from the snow fence to the obstruction located windward of the fence, as illustrated in Figure 7. On the leeward of the snow fence, the location of snow fences against the edge of the roadway will directly determine if the snowdrift approaches the roadway. The length of the leeward snowdrift is the primary factor that influences the siting of the snow fence. In general, the setback of snow fences should not be smaller than the length of snowdrift, otherwise the snowdrift will reach the roadway, making the snow fence ineffective. However, a setback distance that is larger than necessary can result in the "near-snow" problem, where the wind picks up snow on the leeward of the snow fence again and carries it toward the roadway (Heavey, 2013). When using a snow fence with a porosity of 50% on flat terrain, the length of the downwind snowdrift is approximately 35 times the fence height (*H*). Therefore, many researchers recommend a setback distance of 35*H* (Tabler, 1991, 2003). The survey found that this siting guideline has been accepted by most practitioners and DOTs. Considering the typical height of a snow fence, most designs require installation of structural snow fences at least 30 m (100 ft) from the roadway. However, the setback for most snow fences is often limited by the width of ROW. If the 35*H* rule for distance is followed, then the fence may need to be installed on private property, meaning that DOTs must obtain agreements from adjacent landowners. Typically, ROW is a key factor in where the snow fence is ultimately placed.

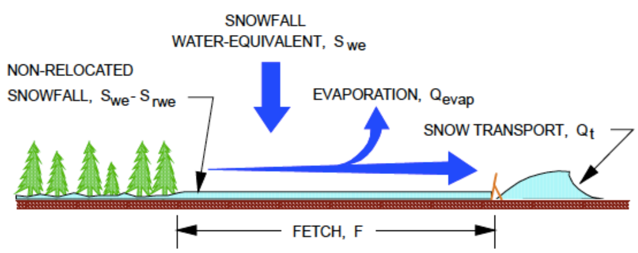


Figure 7. Diagram. Diagram of the fence concept used to estimate wind-transported snow.

Source: Tabler, 2003

Design of Living Snow Fences

LSFs usually consist of planting a combination of trees and shrubs that serve as a windbreak as well as native grasses that act as the snow storage area for accumulating blowing and drifting snow (Figure 8). In addition, rows of corn stalks left at the edge of the field may also be used as LSFs. The same design and siting principles developed for structural snow fences also apply for LSFs. Some modifications are necessary, however, because the height, porosity, and snowdrift length of LSFs change over time as the plants grow (Tabler, 2003; Heavey, 2013).

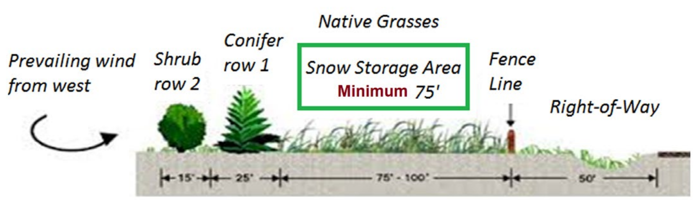


Figure 8. Diagram. Schematic design of a living snow fence.

Source: Wyatt et al. 2012b

Living Snow Fence Configuration

In an LSF, the height of trees is referred to as the "fully effective height" when the snow trapping efficiency reaches 75%. This is the same average trapping efficiency of a structural snow fence during the time from the first snowdrift to the fully filled snowdrift (Tabler, 2003). However, if LSFs grow beyond the fully effective height, the snowdrift may increase during major snow events at areas with narrow ROW (Bramb, 2009). Therefore, proper maintenance of LSFs is necessary to maintain effective fences during their life span. The survey response from Minnesota DOT indicated that fast-growing willows used for an LSF should be cut every three years. One case study found that an LSF with a height of 1.61 m (5.28 ft) can reach a trapping efficiency of 79% when other factors are set at optimum value (Blanken, 2009).

Unlike height, the porosity of an LSF may not always change as the plants grow. Heavey and Volk (2014) found that the porosity decreased linearly for willow LSFs but did not change for conifer LSFs. By planting with adequate between-row spacing, multiple rows of conifers can provide sufficient snow storage capacity for snowdrifts (Shaw, 1989). Iowa DOT planted rows of shrubs in a staggered manner, that is, one row was planted to fill the gap between plants in the adjacent row. Additionally, a spacing of 5 ft between rows and 3 ft apart between plants was adopted to obtain optimum porosity and high trapping efficiency (Bramb, 2009). The North Dakota LSF program found that after roughly 10 years the vegetation reached a sufficient height and porosity to effectively trap snow (Blanken, 2009). However, a study investigated 18 sites of LSFs composed with various vegetation types and ages in New York state and reported that only three years were required for LSFs to obtain the needed height and porosity (Heavey & Volk, 2014).

Another factor that affects the configuration of LSFs is the tree and shrub species selection. The species selection is influenced by various environmental conditions, including soil type, soil pH, drought, and competition between different species (Shaw, 1989; Streed & Walton, 2001). Moreover, in some cases, the trees and shrubs in an LSFs can produce products that may be profitable (Streed & Walton, 2001). For example, the maintenance on willows described above is a source of woody biomass.

Living Snow Fence Location

The length of snowdrifts changes with changing height and porosity of the LSFs, a fact that results in different siting locations compared with structural snow fences. By using the required height instead of the mature height, one study calculated the setback of an LSF and recommended 56.4 m (185 ft), (Blanken 2009). This value may not be accurate because it does not account for the change in the storage capacity-snow transport ratio, Q_c/Q (Heavey & Volk, 2014). If Q_c/Q is less than 1, the storage capacity is smaller than the snow transport, and the snowdrift formed on the leeward of the snow fence will approach the equilibrium drift and consequently features a drift length of 35*H*. In contrast, the length of snowdrift will be less than 35H if Q_c/Q is greater than 1. In this case, the required setback of LSFs can be reduced. As the Q_c/Q changes with the changing height and porosity, the required setback for LSFs is expected to be smaller than that of siting SSFs. By considering the role of Q_c/Q in siting LSFs, the setback distance can be 10 m (33 ft) or less when Q_c/Q exceeds 15 (Heavey, 2013). Iowa DOT research indicated that the snowdrifts downwind from rows of shrubs were trapped in a range of 10*H* to 12*H* (Bramb, 2009). A similar conclusion was found in a corn stalk LSF that mainly stored the snow within the rows of corn and thus needed a smaller setback distance (Nixon et al., 2006). The survey respondent from the Iowa DOT suggested that the LSF should be set back from the edge of the roadway at a distance of 15 times the height of the mature fence. While some agencies recommend setback in terms of fence height, others specify an exact distance that is independent of fence height. Figure 9 shows the setback adopted in the field by agencies according to the survey responses. Generally, it takes years for the LSF to reach the sufficient Q_c/Q to accumulate snow in a narrow setback. In the years prior to that, a temporary structural snow fence can be installed upwind of the LSF to mitigate possible blowing and drifting snow (Heavey & Volk, 2014).

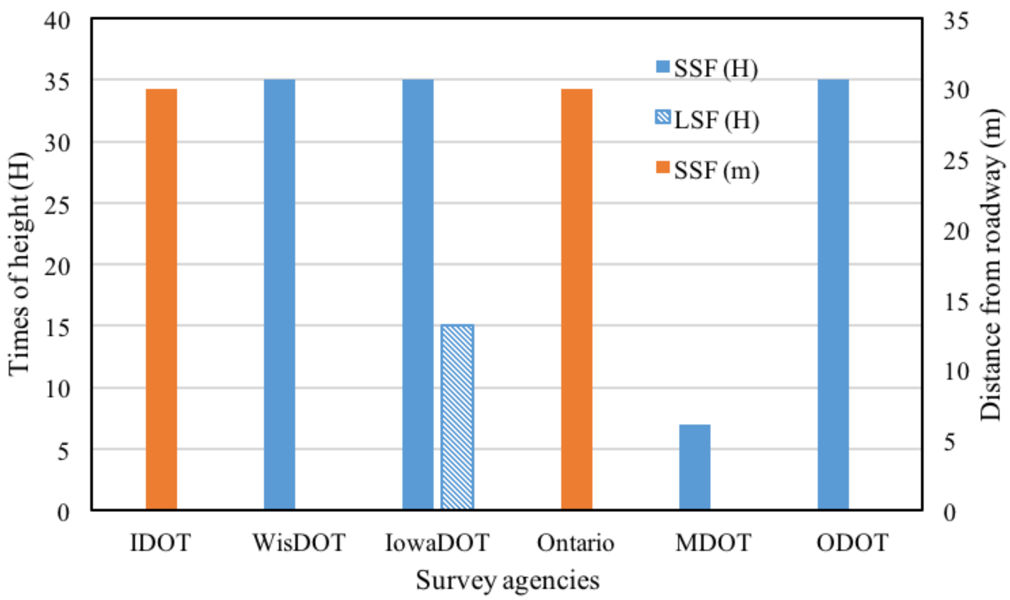


Figure 9. Chart. Setback distance of snow fences adopted by survey-respondent agencies.

BENEFITS AND CHALLENGES OF SNOW FENCES

Snow fences can reduce the wind velocity and change the wind profile. These changes reduce the force of the wind that carries snow particles and allows creeping and saltating snow particles to deposit (Tabler, 1991). The snow is then trapped and accumulates behind the snow fence some distance away from the roadway being protected (Blanken, 2009). Generally, there are three types of snow movement through which the snow is relocated to the ground by wind: creep, saltation, and turbulent diffusion (Mellor, 1965). Large snow particles mainly creep along the surface at low wind speeds and are easily trapped by a snow fence. When average wind speeds exceed 55 km/h (35 mile/h) or so, the creep of large snow particles will disappear (Tabler, 1986). However, only about 20% of blowing snow is transported in this manner at low wind speeds (Tabler, 2003). Most saltating particles are medium snow particles, which appear to jump along the surface and erode the snow surface. Saltating snow particles are also readily trapped by a snow fence. Tabler (2003) reported that most saltating snow particles are contained within 5 cm (2 in.) of the surface when the wind speeds range from 4.0 m/s (14.4 ft/s) to 5.0 m/s (16.4 ft/s). The small snow particles are transported by turbulent diffusion and are suspended in the airstream without contacting the surface. A model study indicates that turbulent diffusion is the main manner of snow transport by wind (Pomeroy, 1989). The suspended snow particles are typically transported higher above the surface and can be trapped by the snow fence only if they settle on the surface (Tabler & Jairell, 1993). By trapping snow particles and preventing blowing and drifting snow from reaching the roadway, snow fences can improve road safety and provide additional benefits. While the benefits of snow fences are clear, some challenges also exist when designing and siting them in practice. The benefits and challenges of both structural and living snow fences are discussed in detail in the following section.

Benefits of Implementing Snow Fences

Benefits of Structural Snow Fences

Structural snow fences can improve road safety and reduce vehicle crashes. Winter crashes are mainly associated with icy roadways caused by blowing snow (Tabler, 2004; Tabler & Meena, 2006). Tabler (1991) reported that accidents were reduced by 70% on roads with snow fences when compared with roads without snow fences. Data from a recent study found a similar conclusion; ground blizzard crashes were almost eliminated on a road that was 90% protected by a snow fence (Tabler & Meena, 2006). After researching the crash data in protected areas, the survey respondent in Wisconsin reported a 69% reduction in winter-related crashes.

Snow fences can also prevent damage to pavement or drainage caused by runoff due to melting snowdrifts (Tabler, 1991). In addition, snow fences result in higher temperatures of the roadway under protection and thus reduce the formation of slush and ice on the roadway. A case study showed that a difference in temperature of 6°C (10°F) was found between the areas with and without snow fences (Tabler, 2003).

Snow fences also deliver positive economic advantages for road maintenance and snow-removal costs, as well as road closures and travel delays (Daigneault & Betters, 2000). A reduction of approximately eight days per year for road closure time was found in a Wyoming snow fence program (Tabler & Meena, 2006). When considering the reduced snow-removal costs alone, a permanent structural snow fence can have a benefit-cost ratio range from 50:1 to 100:1 (Tabler, 2003).

Benefits of Living Snow Fences

Interrupting wind and storing snow are the main purposes of both structural and living snow fences. Relative to structural snow fence, LSFs have the potential to provide greater capacity for storing snow (Shaw, 1988; Daigneault & Betters, 2000). An LSF composed of rows of conifers with adequate spacing between rows could provide sufficient storage capacity in a major storm while a slat or picket snow fence will reach equilibrium capacity quickly (Shaw, 1989). When using rows of corn, the LSF was at least as effective as the traditional SSF with a height of 4 or 6 ft. However, the setback required for the LSF needed was much less than that of a SSF, which will facilitate the adoption in areas with a narrow ROW (Nixon et al., 2006).

In addition to providing similar benefits as structural snow fences, LSFs have other advantages. One critical feature of LSFs is a long service life, which is an important economic advantage (Shaw, 1988, 1989; Daigneault & Betters, 2000). LSFs feature a lower installation cost than SSFs (Shaw, 1989). On average, the total cost (installation, maintenance, and the time required to be fully effective) for establishing an LSF is comparable to erecting a typical wooden SSF. However, LSFs are more cost-effective as they last longer than SSFs (Streed & Walton, 2001). A comparison study indicated that the LSF gave the highest benefit-cost ratio by adopting the costs related to establishment, maintenance, and snow removal, as well as accident reduction benefits (Daigneault & Betters, 2000). In terms of initial investment and maintenance costs, LSFs usually outperform SSFs, which generally require a recurring annual cost for installation and removal between seasons. Table 2 lists the installation and maintenance cost for both SSFs and LSFs established by the survey agencies. The survey results demonstrate that LSFs generally feature a lower labor and material cost.

Table 2. Total Costs for Establishing and Maintaining Snow Fences in Survey-respondent Agencies

Cost	SSF	LSF
WisDOT		$800–$4,000/station
WYDOT	$25–$50/linear feet	$15/linear feet
MnDOT		$30/linear feet
WisBHM	$2,500–$10,000/station	$600–$4,000/station

Note: WisBHM = Wisconsin Bureau of Highway Maintenance

LSFs also result in benefits for the environment and landowners such as providing wildlife habitat, protecting winter livestock, guarding spring calving, and enhancing crop yields (Shaw, 1988, 1989; Daigneault & Betters, 2000; Streed & Walton, 2001). LSFs are expected to increase wildlife diversity in rural areas. Native plantings are usually recommended, as they not only reduce maintenance costs but also control erosion by stabilizing soil along the roadside (Bramb, 2009). LSFs can store carbon, contributing to a reduction in greenhouse gases. Besides the environmental benefits, LSFs can also be profitable to landowners because products can be produced from LSFs (Streed & Walton, 2001). An increased crop yield was found by the Iowa DOT resulting from retaining moisture and reducing drying effects of wind.

The aesthetics is another concern when deciding to establish LSFs. When properly designed, living (vegetated) snow fences integrate with the existing landscape and appear less artificial when compared with structural fences. The aesthetic appeal often motivates the replacement of SSFs with LSFs, particularly for roads in national parks (Blanken, 2009). Visual considerations were reported by survey respondents as motivating factors for selecting LSFs.

Challenges of Implementing Snow Fences

Challenges of Structural Snow Fences

At sites with a narrow public right-of-way, it may be difficult to erect an effective snow fence in the range of ROW, as structural snow fences require greater setback distances. Therefore, SSFs may need to be established on adjacent private land. The main issue that discourages highway agencies from implementing an SSF program is the difficulty in obtaining easements on private land from landowners (Tabler, 1991). Figure 10 shows the frequency of reported challenges for implementing both SSFs and LSFs. Many survey respondents reported that SSFs can only be installed after crop harvest and removed before tillage and planting time. Therefore, agreements with landowners must be obtained every year for temporary SSFs. In addition to the difficulty of obtaining property owner permission, the labor needed to install and remove the fence between seasons is another concern. To encourage farmers to enroll in a snow fence program, the Iowa DOT paid farmers $1 per linear foot for a permanent SSF. Another concern commonly expressed by farmers is that tillage and planting in the spring can be delayed by the presence of snowdrifts (Tabler, 1991). Moreover, landowners prefer planting trees to installing a structural snow fence.

In practice, the survey respondents showed concern regarding maintenance of SSFs. Wood slate fences in the field age and require regular repair and/or maintenance. In some cases, SSF are not properly installed. For example, the fence may not have a sufficient bottom gap. Training of DOT staff is necessary to improve the implementation process for blowing snow control. Another issue reported by survey respondents was that the opening in the fence for vehicles access sometimes created more issues than might have occurred without the fence.

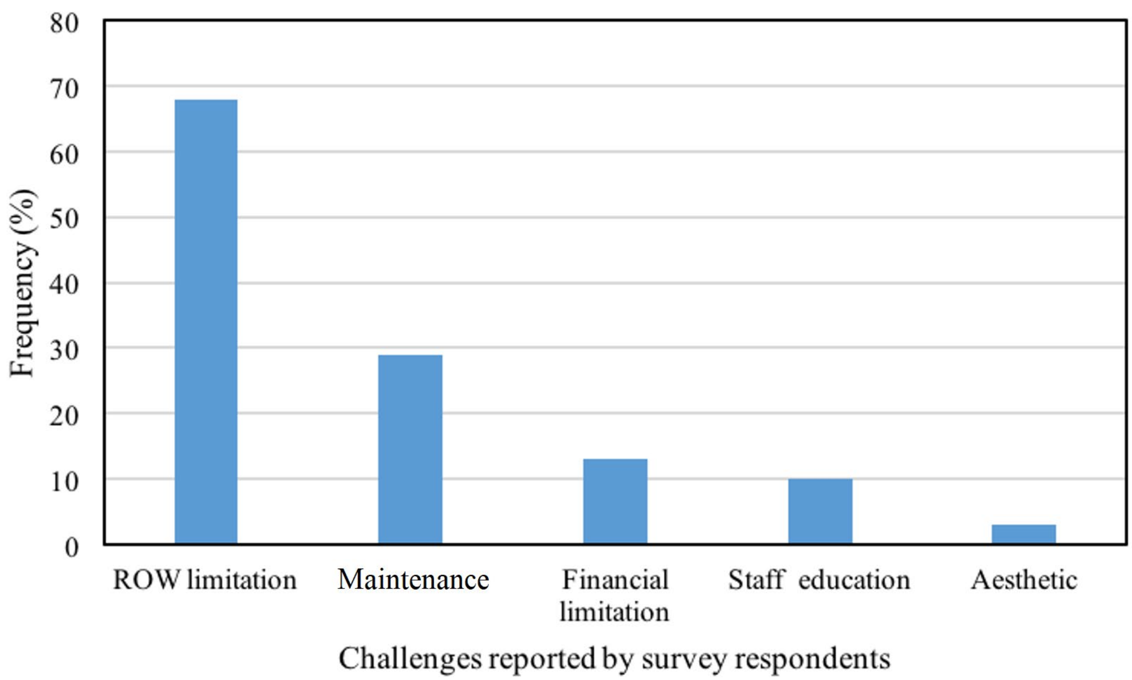


Figure 10. Chart. Frequency of challenges reported in implementing snow fences in the field.

Challenges of Living Snow Fences

The possible challenges of installing LSFs in the field may include agreements with landowners for permanent dedicated land use, time required for plants to become effective, difficulty establishing LSFs on arid or rocky sites, and risks of losing the fence due to insects or disease (Shaw 1988, 1989;

Daigneault & Betters, 2000). From the survey responses, the most frequently reported challenge was obtaining agreements from farmers to give up productive land for planting trees due to a narrow right-of-way. There was strong evidence that economic considerations were the most important factors affecting landowners' decisions (Wyatt et al., 2012b). One program that compensates farmers for their losses in Minnesota is called the Conservation Reserve Continuous Signup Program (CRP) (Streed & Walton, 2001). When partnering with USDA to plant an LSF with a private landowner through the CRP, the Minnesota DOT compensated the landowners $155 per acre for maintaining the snow fence annually over the 15-year life of the CRP contract. Low enrollment in the LSF program in Minnesota DOT necessitated the need to offer more flexible contracts with farmers (Wyatt et al., 2012a). The Iowa DOT also pays landowners who take out farmland and plant snow fences through a program from the USDA's National Resources Conservation Service (Bramb, 2009). The survey results indicated that the Iowa DOT promoted a standing corn program where farmers left rows of corn in the fall that act as a temporary snow fence. The Winter Steering committee calculated the bushels per acre yield and the price per bushel that was then used to pay the farmers. In 2015, the Iowa DOT paid the farmers $5 per bushel, 50 cents over the market rate.

The second consideration for adopting LSFs is the time required after planting until the vegetation reaches a sufficient height and porosity to trap snow effectively. In North Dakota, the required time may be roughly 10 years (Blanken, 2009). The survey response showed that trees appear to be the future, but the slow growth may not provide sufficient protection for at least 4 to 5 years in Wyoming. The experience of another survey respondent indicated that it took 10 years to notice the gradual decrease in roadway snow drifting. There may also be longer term maintenance of the LSFs, including thinning, trimming, fertilizing, and possibly hauling water to plants. Another serious issue is that the function of the LSF may not be recognized, resulting in the removal of the fence by a DOT's own department.

The site climatology and conditions are also critical for planting trees and shrubs. In practice, soil samples should be taken and analyzed to determine if there are trees that will grow in the given soil conditions and other factors, such as elevation and rain pattern. If analysis of the planting site is overlooked, the LSF may die, resulting in snow fence failure (Blanken, 2009). A survey respondent from the Illinois DOT reported that some LSF sections had died and some required pruning. Planting may also be impacted by visual restrictions due to signs or businesses. The experience of the Wyoming DOT showed that grass fires (in the dry climate) can pose a risk and the implementation of LSF in Wyoming thus require proper management of the vegetation. The survey response from the Minnesota DOT indicated that the pattern drain tile in an agricultural setting can limit the use of LSFs due to roots that may interfere with the tile line.

NUMERICAL MODELING OF SNOW FENCES

Designing effective snow barriers requires knowledge of the interactions between wind, snow transport and deposition, topography, and snow fences. At present, little guidance is available to assist practitioners in designing and siting snow fences. Generally, almost all the survey respondents reported a lack of science-based design and siting guidelines for snow fences in practice. Quantitative design tools can be developed with studies in the field, laboratory, or numerically. Field and laboratory approaches may become impractical for design studies because of the high costs and effort required to reproduce the wide range of possible conditions. This is the case with snow fences, where each fence may be comprised of different geometric designs (SSF) or types of plant species (LSF) and is placed in a unique topography, prevailing wind conditions, and roadway geometry. An alternative to direct measurements in the field or laboratory is to approach the problem numerically. Despite some studies on structural snow fences (Basnet et al., 2015), research is lacking in the site-specific design of LSFs to reduce the impacts of snowdrifts. Existing design protocols are based on semi-empirical assumptions about snow transport and deposition around structural barriers, which fail to represent the diverse scenarios around LSFs or guide their proper siting and design (Nixon et al., 2006).

Numerical simulation of snow transport around snow fences requires mathematical models describing the wind, mechanisms of snow erosion and deposition, as well as the influence of the fence on the flow field. Scale, both spatial and temporal, is an important consideration for these models. In snowdrift applications, models may be continuous—simulating large areas over an entire snow season—or event based—simulating a single snow event. Because of the large scales considered, continuous models rely on simplifying assumptions and are often parameterized from field measurements (Walter et al., 2004; Durand et al., 2004; Chen et al., 2009); whereas, event-based models seek to represent the underlying physics of the problem and limit parameterization (Uematsu et al., 1991; Xu et al., 2014). Continuous models may not be sufficient for the problem of snow transport around a snow fence, where local topographic features likely have a significant influence. This difference is highlighted in a study (Chen et al., 2009) where the introduction of a second fence to a continuous model results in the addition of a new equation to represent the effects of the second fence on a snowdrift. In an event-based model, a second fence is part of the geometry, and the flow field around the fences and resulting deposition are calculated without altering the fundamental physical equations. In this approach, the influence of the second fence as well as interaction between fences on wind flow and snow transport and deposition can be investigated without relying exclusively on empirical data.

Computational fluid dynamics (CFD) is a promising tool to model flow and snow transport around structures, including buildings and fences (Uematsu et al., 1991; Sundsbø, 1998; Beyers et al., 2004; Tominaga et al., 2011; Basnet et al., 2015). CFD involves a numerical solution of the governing equations of fluid flow, the Navier-Stokes equations, for a given flow domain geometry and boundary conditions (Ferziger & Perić, 2012). Among the challenges when developing a CFD model of snow fences is accurate representation of the snowdrift processes and the influence of the fence geometry and topography. Two basic approaches for representing snow within a CFD model exist. The Lagrangian, or particle-tracking, approach uses equations describing particle motion to calculate the path of individual snow particles. The primary weakness of this approach is the additional computational effort required to simulate the motion of many individual snow particles. The Eulerian, or multi-phase, approach treats the snow as a second fluid phase. In other words, snow is modeled as a fluid that mixes with the primary fluid, air. The Eulerian approach requires only a single set of additional equations to represent the snow phase. Due in part to this reduced computational effort, most CFD simulations of snowdrift employ the Eulerian approach (Tominaga et al., 2011; Xu et al., 2014). Accurate representation of porosity is critical for numerical simulations because of the important role of porosity in determining fence performance. Prior work has considered flow around manufactured snow fences with regular geometry (Basnet et al., 2015). In this case, the fence geometry was directly incorporated into the numerical mesh. Representing the exact geometry of an LSF is not feasible in numerical modeling due to the range of lengths scales and highly irregular shape of the fence. As an alternative, LSFs can be modeled as a porous media—a solid matrix containing pores that allow a fluid to flow through the matrix. The challenge with this approach is quantifying the impact of the vegetation on the flow field. Guidelines for selecting the parameters required for the porous media approach (e.g., drag coefficient, momentum loss coefficient, permeability, and leaf area density) are not available for the range vegetation used in LSFs. Porous media parameters were determined for a single species at various growth stages performing experiments in a wind tunnel (Sase et al., 2012). While such an approach is promising for modeling LSFs, simulations will continue to require field data for model validation.

SUMMARY

This chapter reports both a review of the literature and responses to a survey focusing on implementing structural and living snow fences to eliminate blowing and drifting snow on roadways. This review combines information obtained from both resources to provide an assessment of snow fences, including the history, design protocols, siting policies, benefits, and challenges of snow fences. Particular attention was paid to living snow fences as an emerging alternative to structural snow fences.

Snow fences have a long history of improving road safety by reducing snowdrifts and blown snow on roadways. Recently, more and more DOTs recognize the benefits of snow fences and are enrolling or planning to implement snow fence programs, especially LSFs.

In such a context, the factors that affect the effectiveness and efficiency were investigated to show the design policies for snow fences. Height, porosity, and length of a snow fence are the main design parameters, while the bottom gap and wind direction should also be considered. Besides the correct design factors, the siting location is another important consideration to ensure that the snow fence prevents snowdrifts reaching the roadway. The same design and siting principles developed for structural snow fences also apply for LSFs; some modifications, however, are necessary because the height, porosity, and snowdrift length of LSFs change over time as the plants grow.

If designed and sited properly, snow fences can improve road safety and provide other benefits. LSFs are preferred by both DOTs and farmers because they are more cost-effective and beneficial to the environment and landowners. However, some challenges exist when installing snow fences on private land in areas with a narrow right-of-way. The greatest challenge facing snow fences is the difficulty in obtaining agreements with landowners to establish fences on productive land. Some DOTs have found success establishing specific programs to compensate farmers.

CHAPTER 3: RESOURCE EXPENDITURES

The research team conducted a review of IDOT's data of snow and ice removal costs to determine the extent of resource expenditures dedicated to keeping roads open and to dealing with blowing snow. First, 2010–2019 data of the total snow and ice removal cost in Illinois were acquired and compiled. Then, a team section survey was conducted to gather information on the blowing snow segments across Illinois. Last, data of the blowing snow removal cost in Illinois for the 17–18 and 18–19 winter seasons were acquired and compiled. Bar charts were developed to show the expenditure trend over time and across different districts in Illinois.

TOTAL SNOW AND ICE REMOVAL EXPENDITURES

The 2016–2017 winter weather facts sheet, AMP Snow and Ice Control Storm Report (R054), and weekly snow and ice report 2017–2019 were acquired from IDOT. The 2016–2017 winter weather facts sheet contains data for the following items for each district and the state total:

- Labor expenditure
- Equipment expenditure
- Material expenditure
- Total trucks
- Required trucks—Single-axle dump
- Required trucks—tandems
- Required trucks—4x4s
- Required trucks—Rotary snowplows
- Lane miles plowed
- Number of counties served
- Permanent employees available for snow removal
- Temporary employees
- Number of truck routes

The 2017–19 weekly snow and ice reports contain data of the following items for each districts and state total:

- Labor expenditure
- Total labor hours
- Equipment expenditure
- Material expenditure
- Total expenditure
- Salt usage
- Salt on hand as % of capacity by district

The 2017–19 weekly snow and ice reports also contain data of the following items for the state total:

- Total maintenance cost (labor)
- Total maintenance cost (equipment)
- Total maintenance cost (material)
- Overtime cost
- Extra help cost
- Fuel consumption on-road equipment
- Total fuel consumption
- Total fuel cost

The AMP Snow and Ice Control Storm Report (R054) contains data of lane miles plowed for each district and the state total.

The acquired data were compiled in an excel worksheet (Appendix A). Note that some cells in the Excel worksheet are not populated, because not all data items have data for each district. Among all data items, the labor, equipment, and material costs are of great interest for this study. Even with some variation, the table shows that the winter maintenance costs in labor, equipment, and material have been increasing over 2015–19 for each district and the entire state, particularly for districts 2, 3, 4, and 5, which have the most severe blowing snow issue along their highways in Illinois.

BLOWING SNOW SEGMENT SURVEY

In order to know where typical blowing snow problems are and how many lane miles that typically blow, a survey questionnaire was developed and distributed to operation supervisors and field engineers across the state. Herein, the blowing snow problem locations are defined as any location where operation teams must clean up blowing snow after the snow has stopped falling. This may be due to drifting and more plowing is needed or blowing and the team cannot safely leave the route until the snow stops moving across the road. The survey questionnaire was developed to gather information on team sections, routes, and rough lane miles that typically are prone to blowing snow. The identified segments will be places where some sort of snow fence could be beneficial in the future. The survey instrument is shown in Appendix B.

With the help of TRP Chair Rod Lashuay and former winter operation engineer Frank Sharpe, the survey questionnaire was circulated among IDOT operation supervisors and field engineers of all nine districts during the 2016–17 winter season and the responses were compiled in an Excel file. Table 3 shows the summarized statewide blowing snow segments based on the data provided by team sections who responded to the survey, while Tables 7–13 in Appendix B present the blowing snow segments for each district. Note that district 6 and district 8 did not report any blowing snow segments and not all team sections in the remaining districts responded to the survey. The survey data indicate that districts 2, 3, 4, and 5 have most of the blowing snow lane miles in the state, with the percentage of route with blowing snow from 30% to 50%. The results match the winter maintenance expenditure data from the previous section.

Table 3. Statewide Blowing Snow Segments

Total Lane Miles of Route	Interstate Miles	Non-Interstate Miles	Interstate Blowing Snow Miles	Non-Interstate Blowing Snow Miles	% of Route with Blowing Snow
13,465.67	2,398.71	11,066.96	789.40	3,871.76	34.6%

BLOWING SNOW REMOVAL EXPENDITURE

To identify the winter maintenance expenditure for dealing with blowing snow along Illinois highways, IDOT’s snow and ice removal cost-reporting system added a new function to gather this data starting in the 2016–17 winter season with the help of former winter operation engineer Frank Sharpe and TRP Chair Rod Lashuay. Total blowing snow removal expenditure data (labor, material, and equipment) of all nine districts for the 2016–17, 2017–18, and 2018–19 winter seasons were received from IDOT. After compiling the data, bar charts were developed to compare the total snow and ice removal expenditure and blowing snow removal expenditure for each district and different team sections within districts 2, 3, and 5.

Figures 11–13 present the total winter snow and ice removal costs, blowing snow removal costs, and the percentage of blowing snow removal cost among total winter operation costs per district, respectively. They show that districts 2, 3, and 5 have higher percentages of blowing snow removal costs than other districts for the reported three winter seasons. Note that 2016–17 is the first season to collect blowing snow cost data, and the data is not complete for each district. Therefore, the 2016–17 data may not reflect the real trend or pattern of blowing snow expenditures.

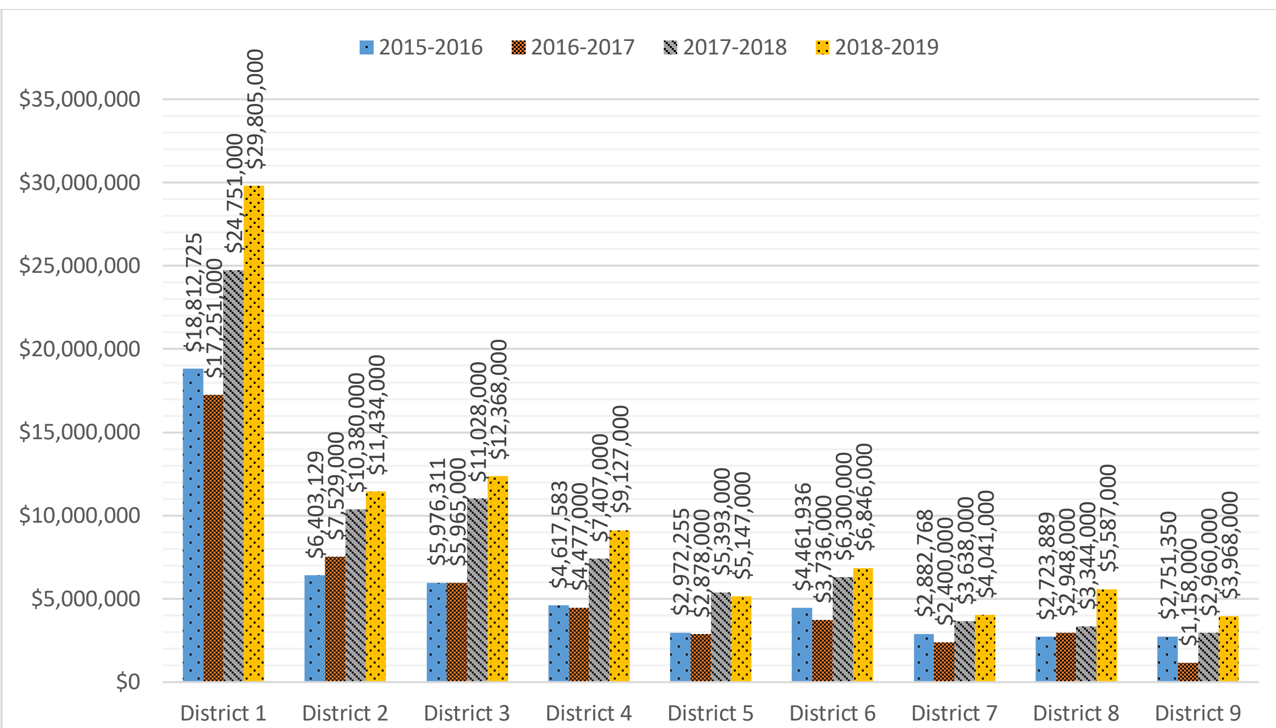


Figure 11. Chart. Total winter snow and ice removal cost per district.

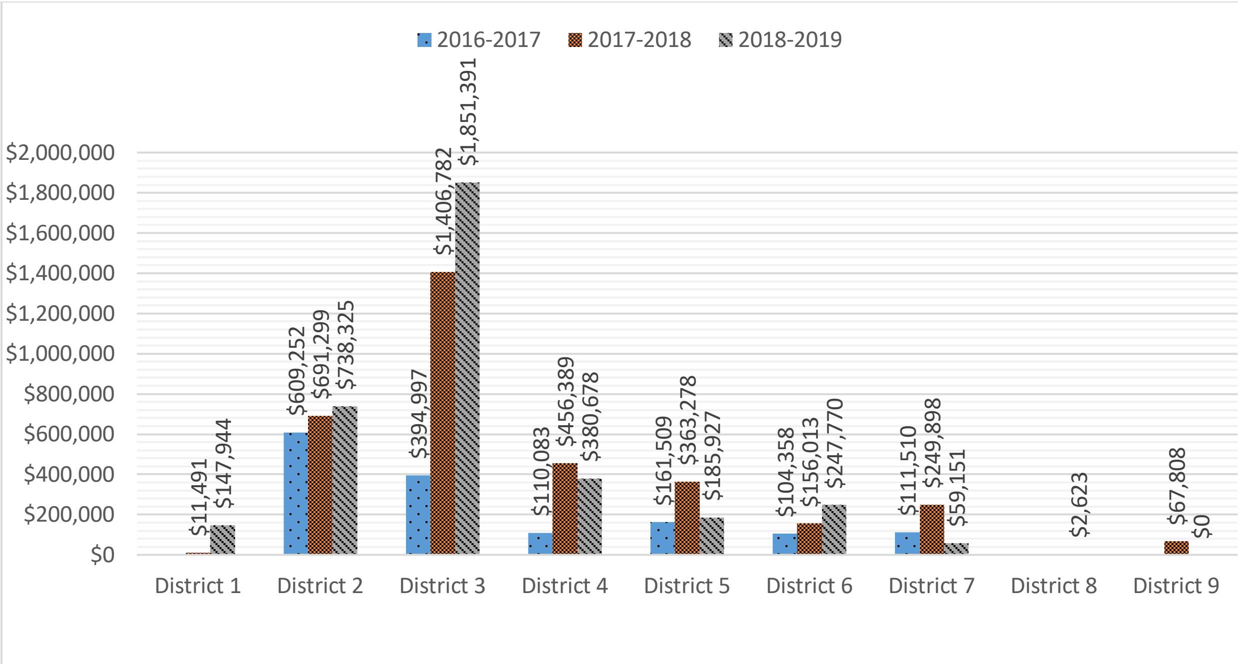


Figure 12. Chart. Total blowing snow and ice removal costs per district.

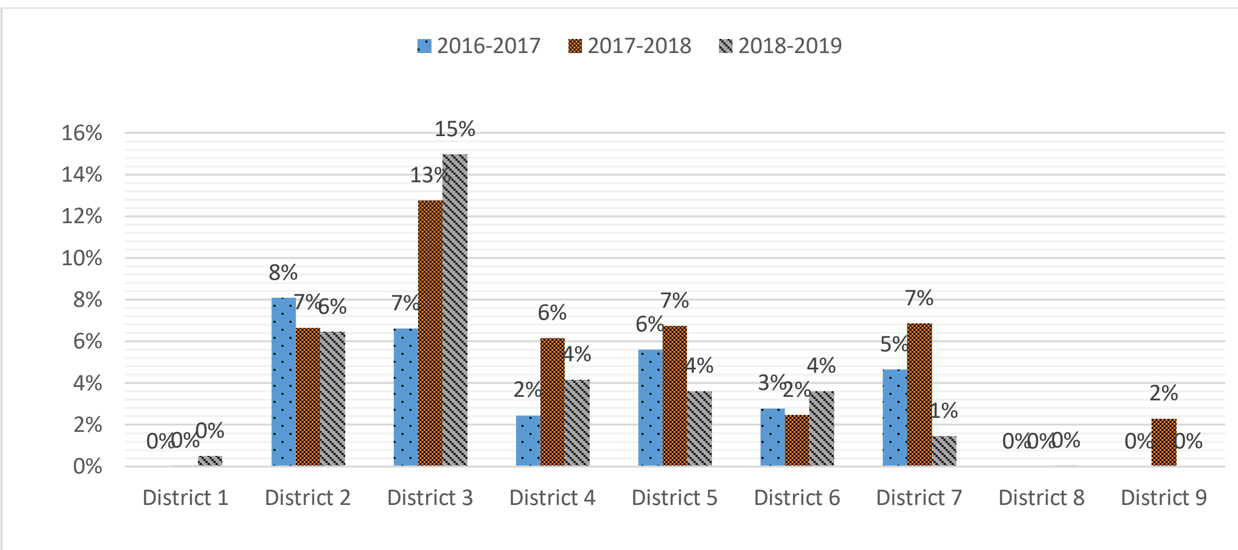


Figure 13. Chart. Percentage of blowing snow removal costs among total winter operation costs per district.

In addition, bar charts (Figures 14–19) of total snow and ice removal costs and blowing snow removal costs per team section in districts 2, 3, and 5 for the 2018–19 season were developed. There are large variations among team sections in terms of total snow and ice removal and blowing snow removal costs for the three districts. Team sections with high total snow and ice removal costs did not match those with high blowing snow removal costs. This may be due to the different locations, orientations, and surrounding area features (open area), etc. of highways in different team sections. In district 2, Amboy is the team section with the highest blowing snow removal cost; the remaining team sections are far behind it in this regard. In district 3, Ottawa, Princeton, and Kankakee are the top-three team sections in terms of blowing snow removal expenditures, while in district 5, Champaign, Fithian, and Tuscola are the top-three team sections.

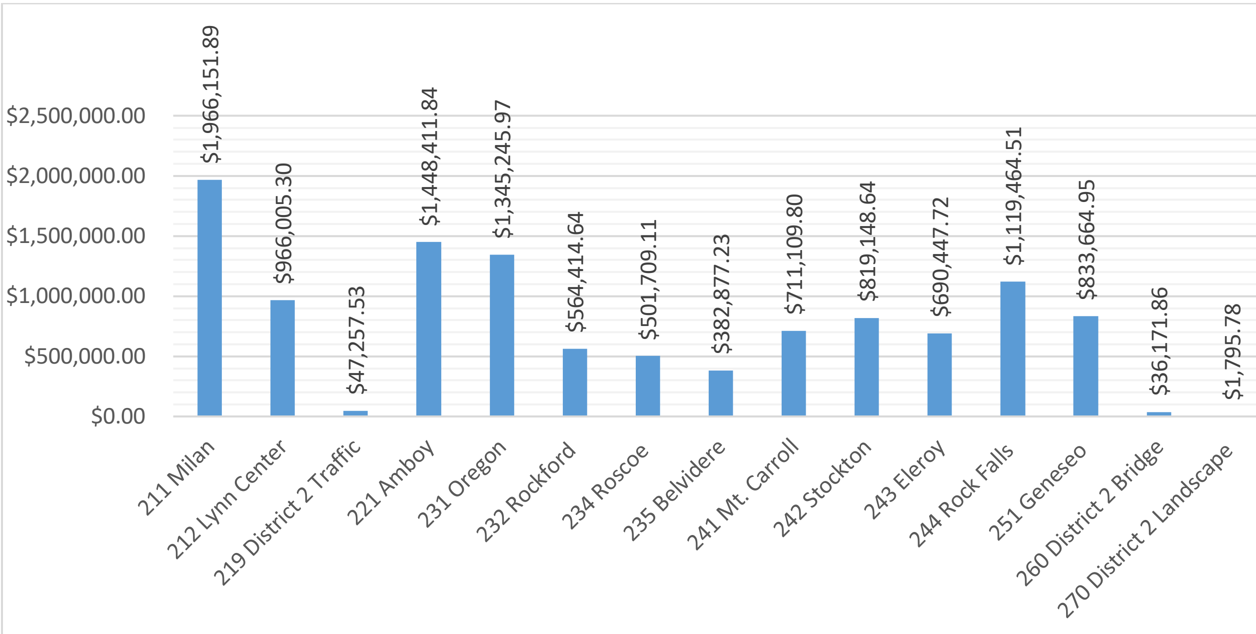


Figure 14. Chart. District 2 winter snow/ice removal cost per team section in 2018–19.

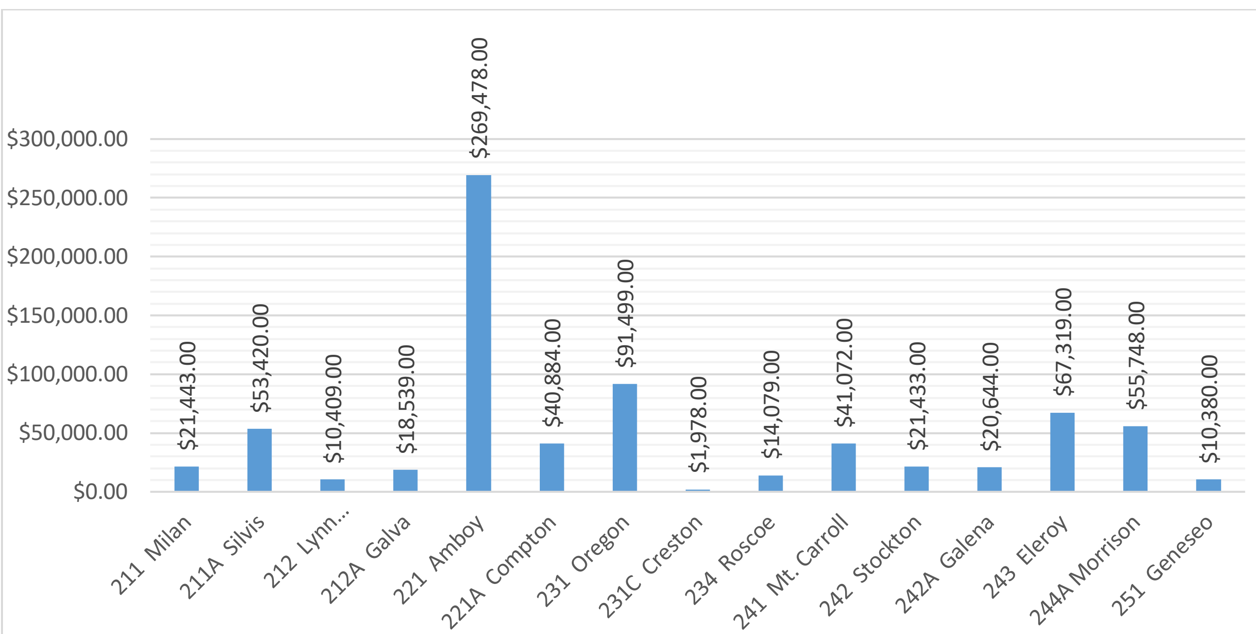


Figure 15. Chart. District 2 blowing removal cost per team section in 2018–19.

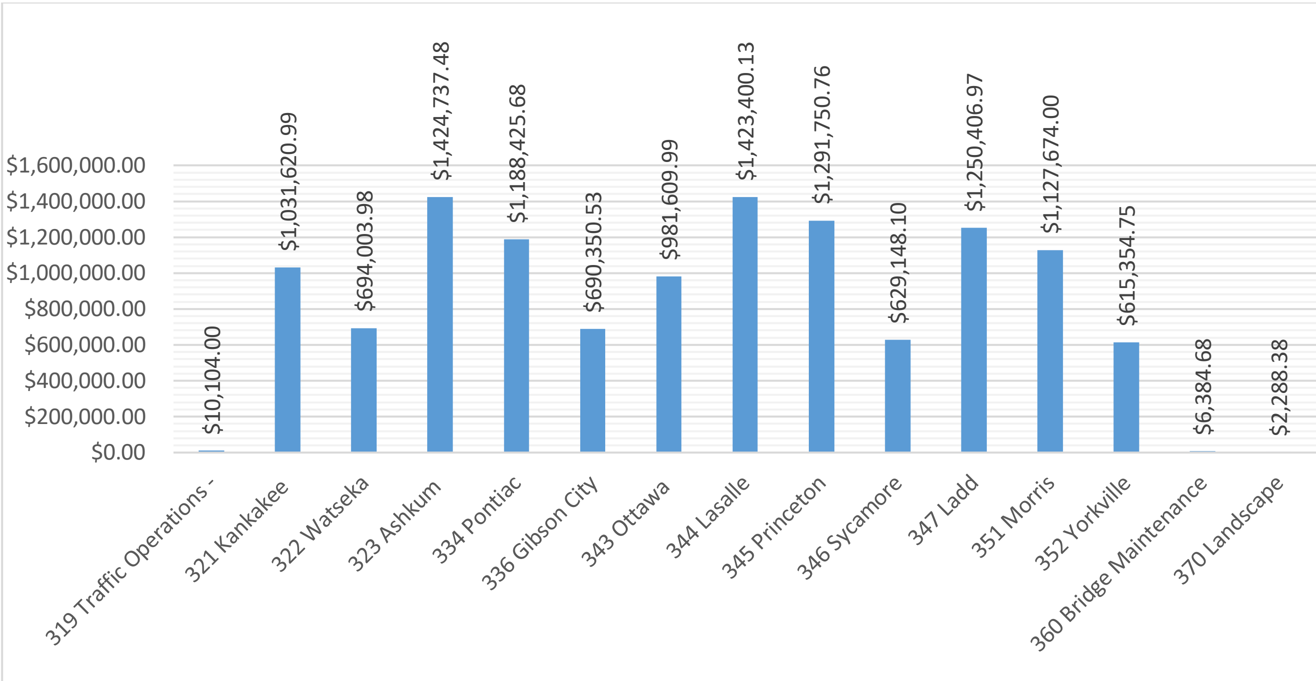


Figure 16. Chart. District 3 winter snow/ice removal cost per team section in 2018–19.

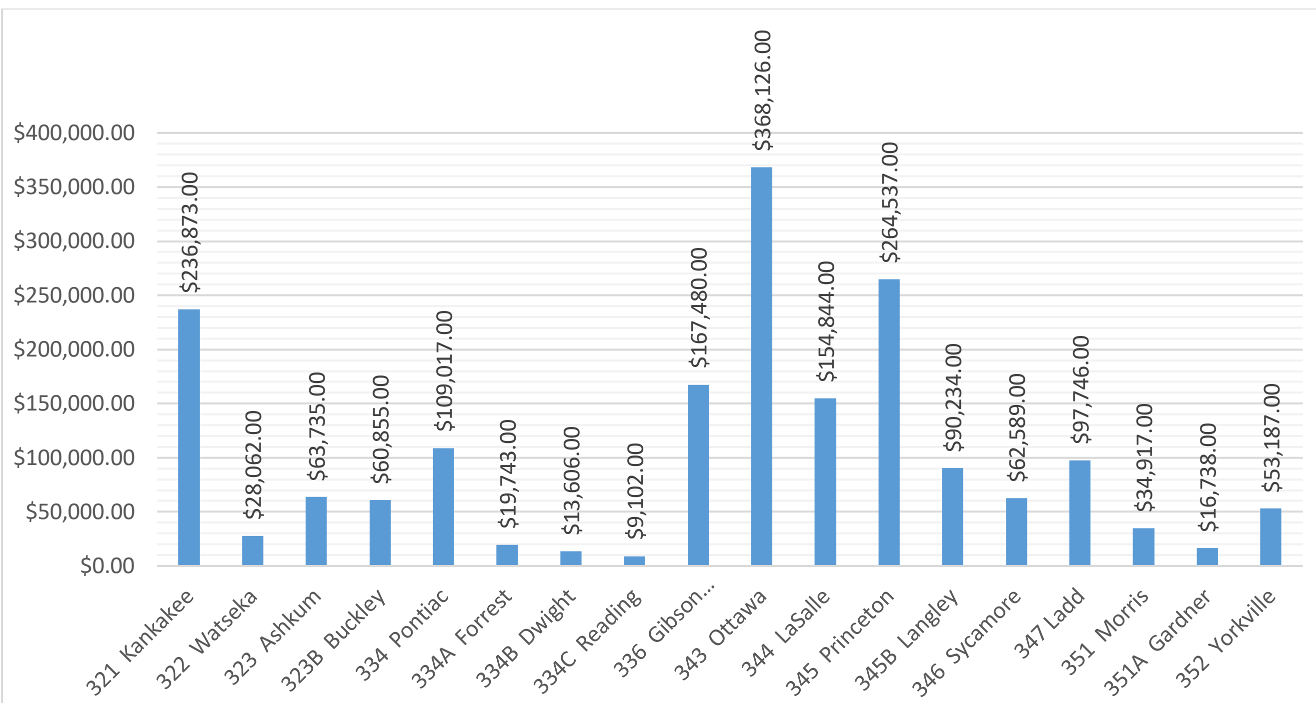


Figure 17. Chart. District 3 blowing removal cost per team section in 2018–19.

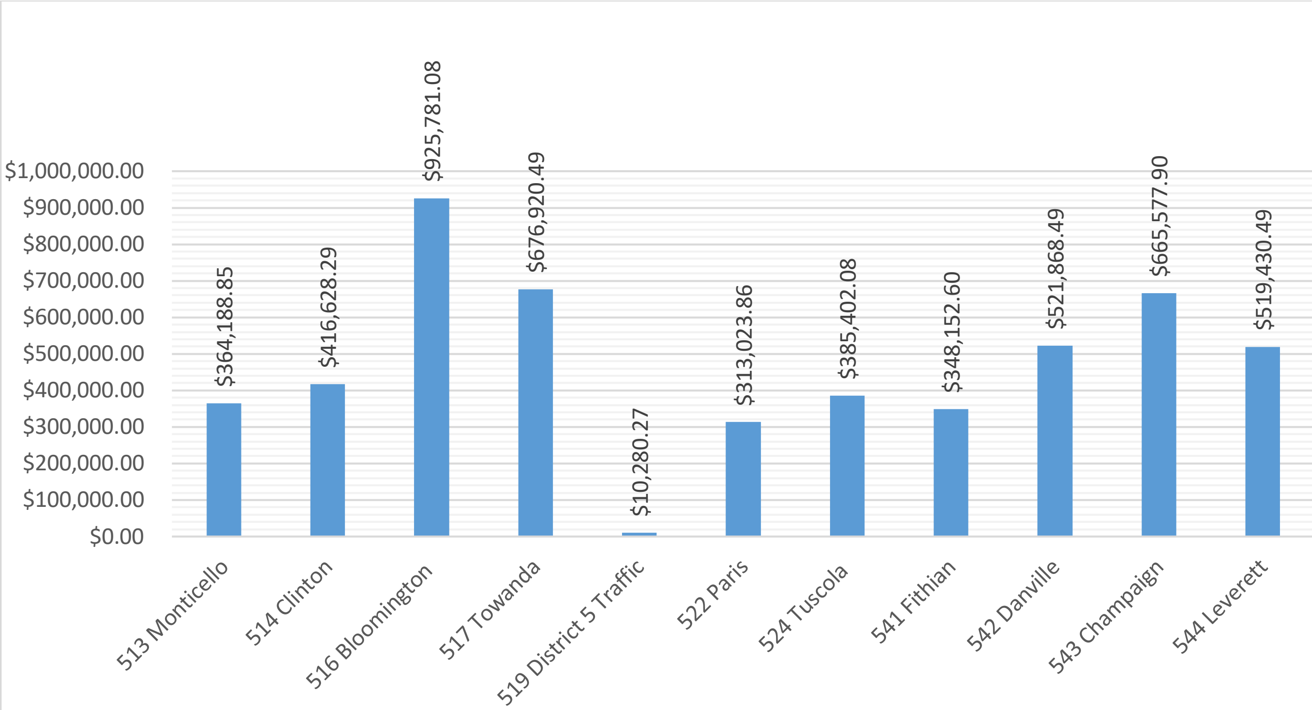


Figure 18. Chart. District 5 winter snow/ice removal cost per team section in 2018–19.

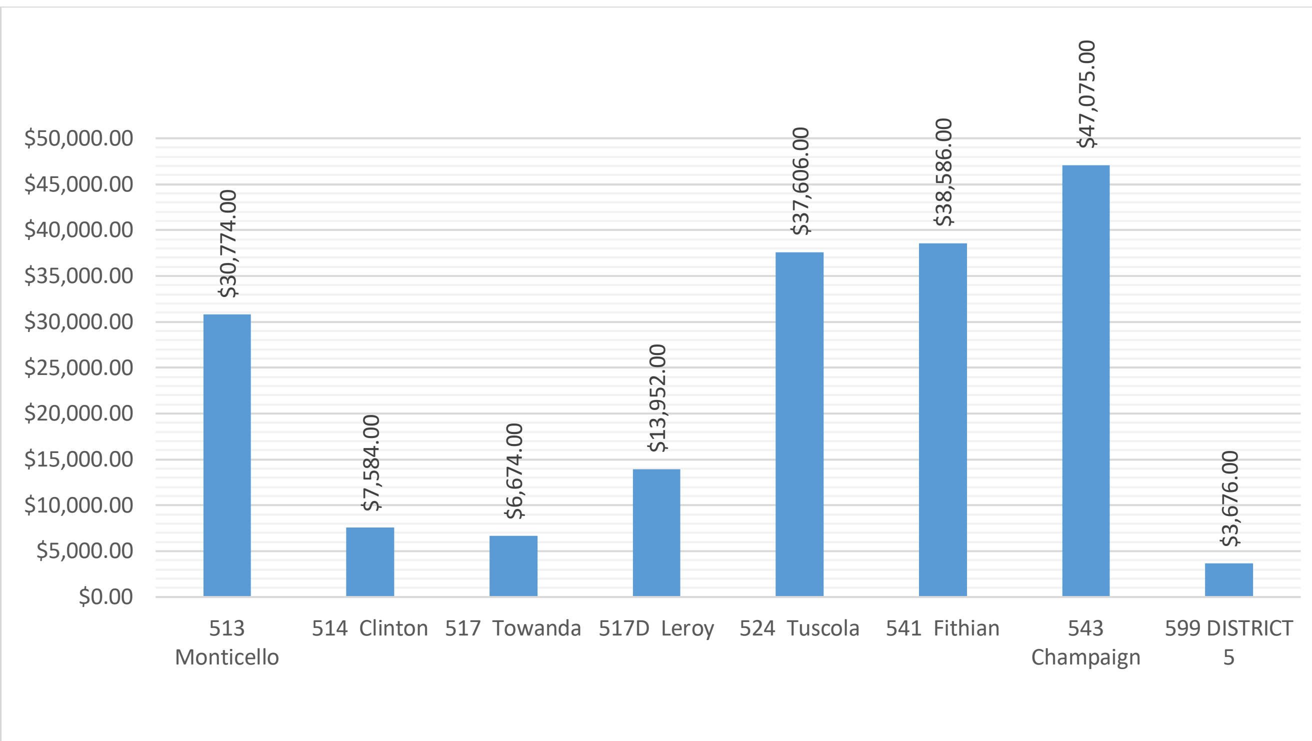


Figure 19. Chart. District 5 blowing removal cost per team section in 2018–19.

SUMMARY

District and statewide winter snow and ice removal expenditure data were acquired and compiled. Labor, equipment, and material costs are of great interest in the study. Although the winter weather severity (e.g., number of snow events, snow precipitation, wind speed, and duration) is the main influential factor and it varies from year to year, the winter snow and ice removal labor, equipment, and material expenditures have increased in general over the 2015–16 to 2018–19 winter seasons. Among all nine districts, district 1 has the highest winter operation expenditures ($17,251,00 to $29,805,000), followed by districts 2, 3, 4, 6, 8, and 5 ($6,403,000 to $12,368,000).

To examine the impacts of blowing snow on winter operations, an internal survey was conducted to gather information on the location and lane milage of segments with blowing snow problems, and IDOT has started to collect blowing snow expenditure data separately since the 2016–17 season. Although not all team sections responded to the survey, the data from those that responded show that districts 2, 3, 4, and 5 have a higher percentage (30–50%) of blowing snow segments than other districts. It matches the total winter snow and ice removal cost data, indicating blowing snow costs account for a large part of the total winter maintenance expenditure. This was confirmed by the blowing snow removal cost data. The data also show high variation and different patterns in total winter operation expenditure and blowing snow removal cost within each district. This may be due to the different locations, orientations, and surrounding area features (open area), etc. of highways in different team sections.

CHAPTER 4: MODELING SNOW DRIFTING AROUND LIVING SNOW FENCES

Numerical simulations of flow around porous fences were performed using Flow-3D, a computational fluid dynamics software. The experimental data from a wind tunnel study of a nonuniform porous fence was used to validate the modeling approach. Following validation, the numerical approach was used to test a model for fence porosity and investigate the effect of row spacing for fences comprised of two rows of vegetation.

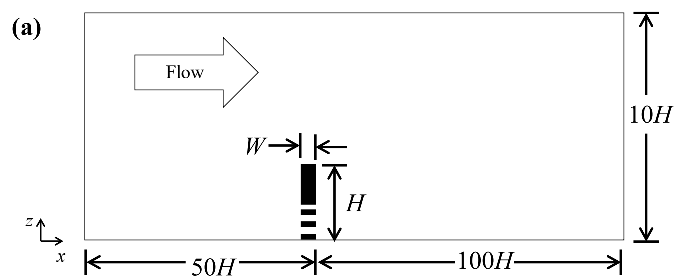
MODEL SETUP

Airflow around a fence can be considered a two-dimensional, steady flow of an incompressible fluid. To model airflow around a fence, the CFD software numerically solves the fundamental equations of viscous fluid motion in the form of conservation of mass and conservation of momentum, together known as the Navier-Stokes equations. In particular, the time-averaged equations, known as the Reynolds Averaged Navier-Stokes equations, are solved with the addition of a turbulence model. The turbulence model determines the effects of turbulent fluctuations on the average flow field. All simulations used the standard Renormalization Group k-ε turbulence model (Yakhot et al., 1992). For 2D simulations, airflow perpendicular to the fence was modeled. In this case, the flow domain was selected to capture the influence of the fence on the flow above and downwind of the fence. The flow domain shown in Figure 20-A was used in the simulations. The boundary conditions for this domain are illustrated in Figure 20-B and include a velocity inlet, pressure outlet, wall boundary, and symmetry boundary. The flow domain was discretized using a nonuniform Cartesian mesh such as the example shown in Figure 21. For all simulations, the mesh size decreases in the vicinity of the fence to capture the flow changes around the fence. Additionally, the near-wall mesh size was selected to produce a y+-value greater than 30, as required by the turbulence model. Simulations were deemed complete when the flow became steady. Flow was considered steady when the variation for successive iterations was below 1.0% for total mass, average mean kinetic energy, average mean turbulent energy, and average mean turbulent dissipation. The model techniques and settings described above were used first for validation simulations then, once validated, for a series of simulations to support the design of LSFs.

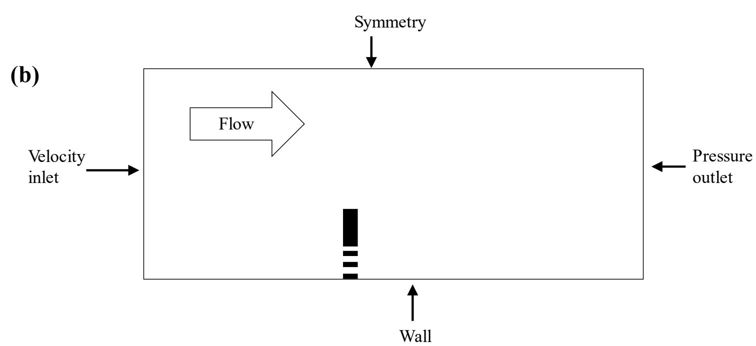
MODEL VALIDATION

Living snow fences often have a nonuniform distribution of porosity in the vertical direction. For example, fences comprised primarily of trees may have a region of high porosity near the ground surface (where the solid trunks are spaced intermittently) underneath the lower porosity produced by the dense network of branches and leaves. Experimental data for such cases is limited with an exception being the experiment of Huang et al. (2012). In this experiment, vertical velocity profiles around a fence with a nonuniform distribution of porosity were measured in a wind tunnel. The fence height was H = 0.06 m and the top half of the fence was a solid wall (porosity of 0) while the bottom half had a porosity of 0.30. The wind tunnel had dimensions of 0.6 × 0.6 × 8.0 m and was wide enough that the effect was negligible at the centerline. The uniform inflow velocity was U_o = 10.6 m/s, resulting in a Reynolds number of about R_{eH} = 4.1 × 10^4. Huang et al. (2012) report mean streamwise velocity profiles measured with a hot-wire anemometer. Profiles were measured at horizontal locations of x/H = −4, −2, 0, 1, 3, 6, 9, 12, 15, 18, 21, 25, 30 (fence is located at x = 0 m).

To validate the numerical approach, the experimental conditions of Huang et al. (2012) were reproduced and simulated in Flow-3D. The experimental flow conditions can be considered two-dimensional and steady. The numerical flow domain extended a distance of 50*H* upwind of the fence and 100*H* downwind of the fence. The height of the flow domain was 10*H*. The bottom boundary was a no-slip wall and the top was a symmetry boundary. The outflow boundary was a pressure boundary and the inflow boundary was a fully developed velocity profile with a mean velocity of 10.6 m/s. Figure 20 illustrates flow domain, geometry, and boundary conditions. The flow domain was discretized with a nonuniform Cartesian mesh with 70,278 cells. The near-wall cell size in the vertical direction was selected to produce a y^+-value greater than 30 and less than about 41. Figure 21 shows a detailed image of the fence geometry and numerical mesh. The simulation was considered converged when the total mass, average mean kinetic energy, average mean turbulent energy, and average mean turbulent dissipation changed by less than 1.0%. This small variation in parameters is indicative of steady-state conditions.



A. Flow domain and geometry.



B. Boundary conditions for simulations.

Figure 20. Diagram. (a) Flow domain and geometry and (b) boundary conditions for simulations based on the experiments of Huang et al. (2012). Drawings not to scale.

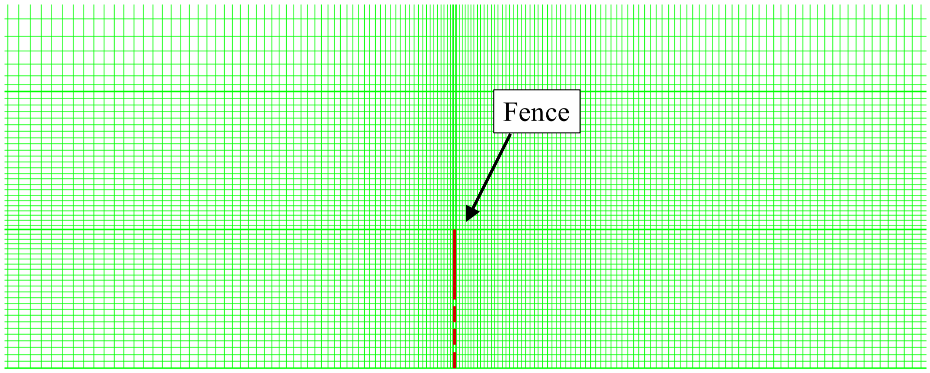


Figure 21. Diagram. Fence geometry and numerical mesh for simulations based on the experiments of Huang et al. (2012). Flow is from left to right.

Figure 22 shows the flow field produced by the numerical simulation. Additionally, the flow field resulting from a solid fence with the same geometry and flow conditions is provided. Comparing the two fences demonstrates key features of the porous fence. The flow behind the porous fence is characterized by a region of relatively higher velocity in the lower half of the fence. As a result of this feature, snow is transported through the fence and encounters a low-velocity region that causes snow to settle. The absence of this feature in the solid fence means that snow is either deposited on the windward side of the fence or carried over the fence. Once past the fence, the transported snow is located in a region of relatively high velocity, reducing the potential for snow to deposit. Additionally, the velocity above the fence is larger for the solid fence than for the porous fence, indicating a higher capacity to transport snow over the solid fence. A region of low velocity and recirculation forms on the windward side of the solid fence as the wind encounters the impenetrable barrier. While velocity also decreases on the windward side of the porous fence, the velocity decrease is smaller because the air can pass through the fence.

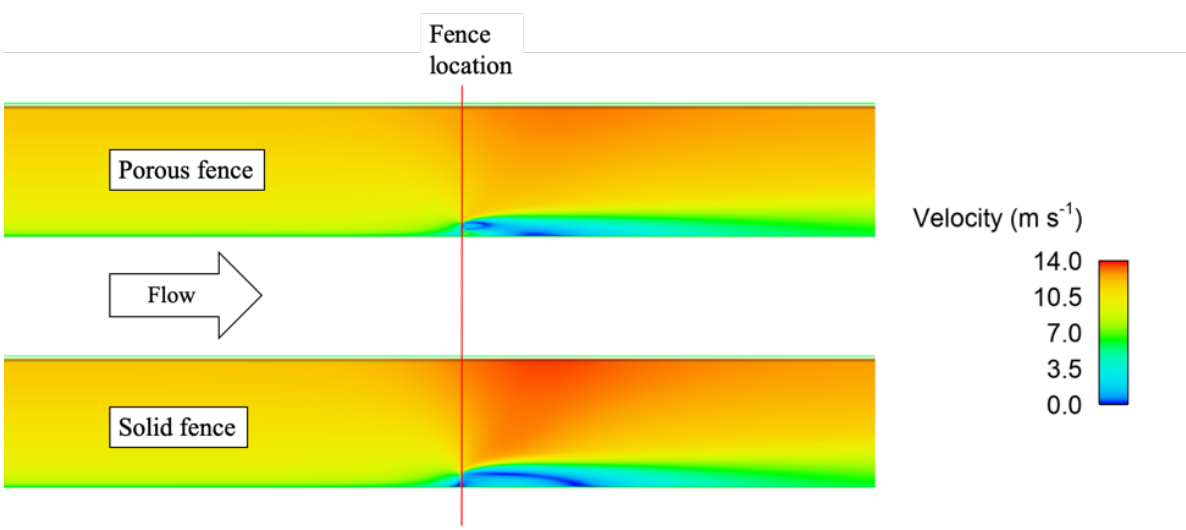


Figure 22. Diagram. Contours of velocity magnitude from numerical simulations of (a) a fence with nonuniform porosity (top half, θ = 0; bottom half, θ = 0.3) and (b) a solid fence (porosity, θ = 0).

Profiles of the velocity in the *x*-direction, or streamwise velocity, produced by the simulation are compared with the measured values in Figure 23. As with the experiments, the fence is located at *x*/*H* = 0. Generally, the numerical results are in good agreement with the experiments. Differences are seen in the region close to the fence, for example at locations *x*/*H* = 0 and 3, below *z*/*H* = 1.0. Behind the fence is a region of complex flow that is difficult to reproduce numerically and measure experimentally. Despite the difference in magnitude predicted in this area, the qualitative flow pattern is similar. Away from the fence, the numerical solution reproduces the measured profiles well for *z*/*H* less than about 2.0. Above this location, the numerical model slightly overestimates the velocity. The region within two fence heights is most important for design and analysis of snow fences. For this reason, the numerical simulation is adequate to reproduce the experimental results and can be used for further investigations of snow fence behavior.

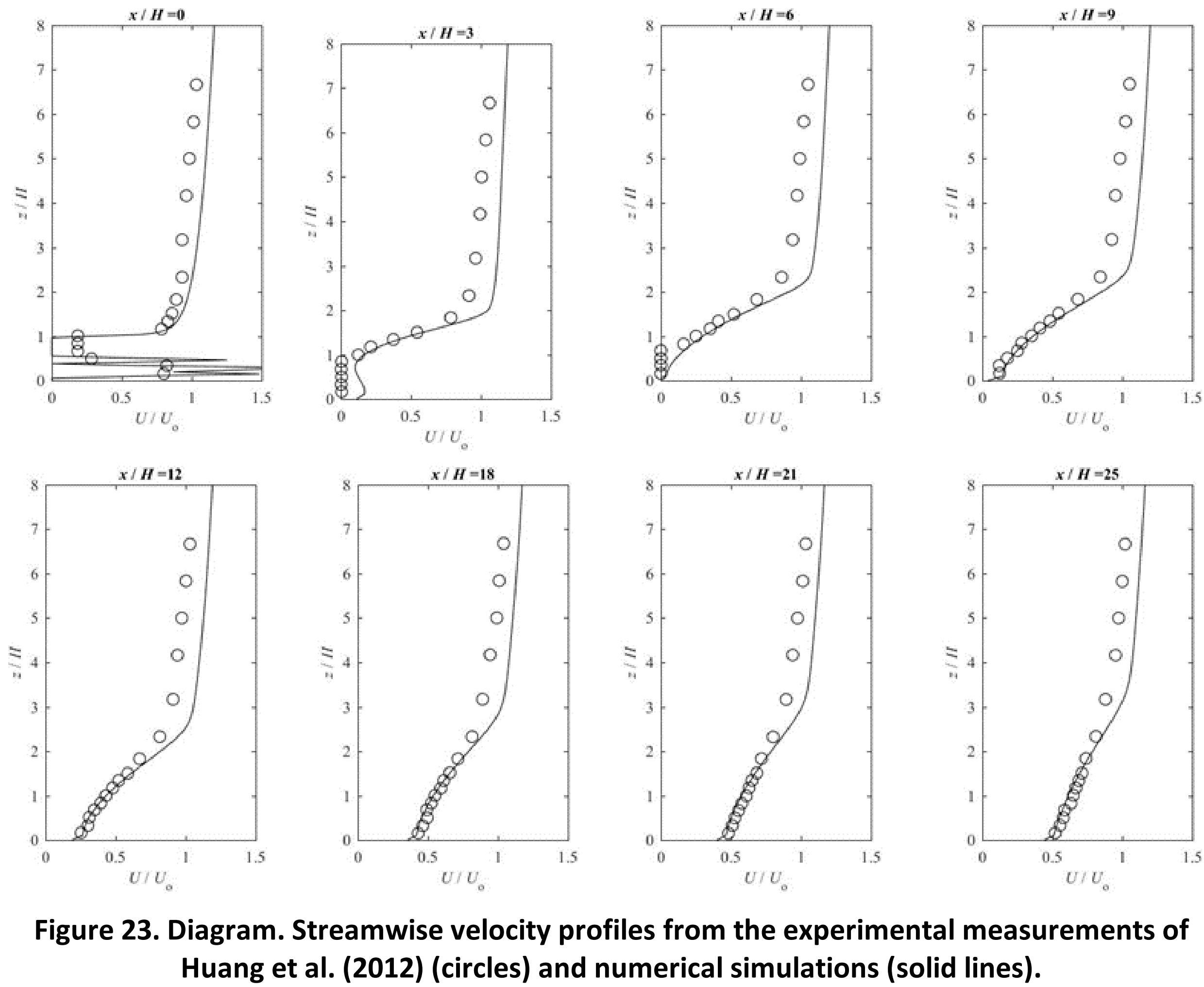


Figure 23. Diagram. Streamwise velocity profiles from the experimental measurements of Huang et al. (2012) (circles) and numerical simulations (solid lines).

POROSITY MODELING

Representing the true porous fence geometry is difficult for LSFs. The irregular nature of vegetation requires very small cell sizes, increasing computational effort. An alternative approach is to model the bulk effects of porosity on the flow field using the Darcy-Forchheimer equation along with an equation representing the resistance characteristics of the porous fence. To test this approach, a numerical simulation was performed using the Darcy-Forchheimer and Ergun equations for flow resistance. The Ergun equation was developed to describe flow through a bed of packed spheres. The drag coefficients were determined replacing the sphere diameter with the height of the slats in the porous section of the fence and using the recommended values for the constants, α = 150 and β = 1.75. This approach produced drag coefficients on A = 3,061,224 and B = 250. In this simulation, only the representation of the porous portion of the fence changed. The flow domain, fence geometry, mesh, and boundary conditions were identical to the validation case described above.

The contours of velocity magnitude shown in Figure 24 demonstrate that the porosity model reproduces the qualitative flow features of the porous fence. While the horizontal extent of the low velocity region is similar for both approaches, the porosity model produces slightly lower velocity magnitudes in this region. The porosity model also predicts higher velocity magnitudes above the fence. These qualitative observations are confirmed by the velocity profiles. As seen in Figure 25, the porosity model predicts lower velocity behind the fence, e.g., at x/H = 3, 6, 9, and 12 below z/H =2.0. Additionally, the porosity model slightly overpredicts velocity above z/H = 2.0 at x/H = 6 and 9. As the distance from the fence increases, the two approaches produce essentially the same results. While the porosity model results could be improved by modifying the drag coefficients, the results demonstrate that the recommended values for the Ergun equation produce reasonable results when compared to both simulations, representing the actual porous geometry and measured experimental data.

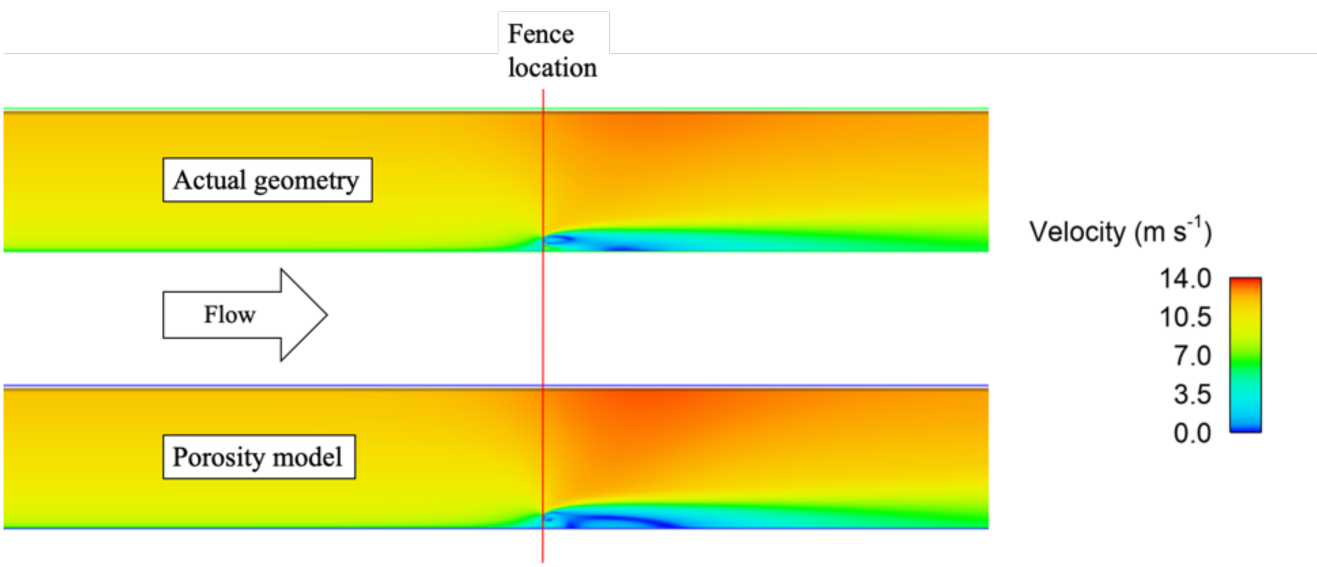


Figure 24. Diagram. Contours of velocity magnitude from numerical simulations of a fence with nonuniform porosity representing the porosity with the actual geometry and a porosity model.

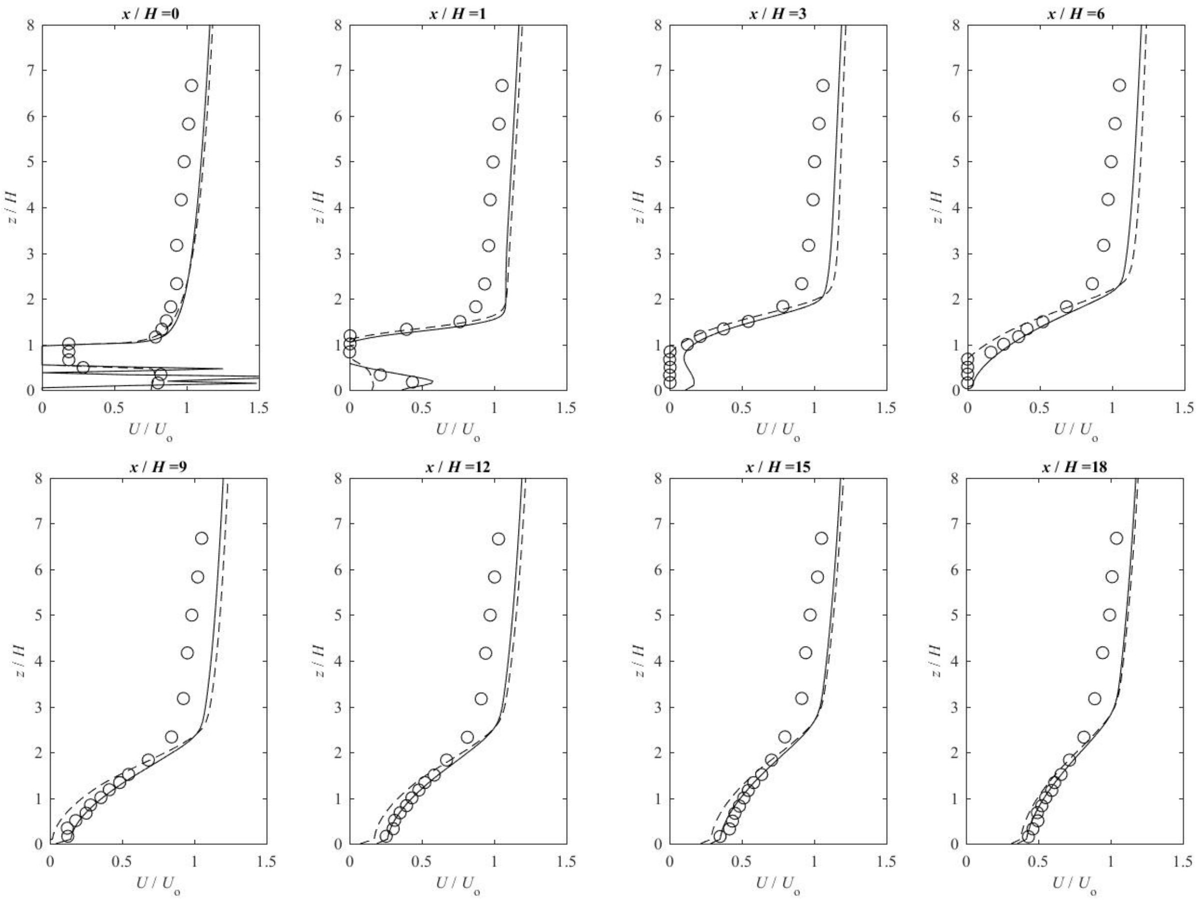


Figure 25. Diagram. Streamwise velocity profiles from the experimental measurements of Huang et al. (2012) (circles) and numerical simulations representing the actual fence geometry (solid lines) and using a porosity model (dashed lines).

INFLUENCE OF FENCE SPACING

Vegetation may be planted in rows to form a LSF. To test the effect of row spacing, a series of simulations were performed using two identical fences separated by distances of 0.5*H*, *H*, 2*H*, 3*H*, 5*H* and 10*H*. The geometry of each individual fence was identical to the fence used in the validation simulations based on Huang et al. (2012). The flow domain and boundary conditions were also the same as for the single fence simulations. The mesh was modified to ensure the same distribution of cells around both fences. Figure 26 provides an example of the two-fence geometry and near-fence meshing.

Figure 27 shows the contours of velocity magnitude for a single fence and two fences. The flow around two fences is qualitatively similar to the flow around a single fence with the addition of a low-velocity region in between the two fences. Streamwise velocity profiles for two fences at close spacing (0.5*H*, *H*, 2*H*, and 3*H*) are compared with those for a single fence in Figure 28. In this figure, the *x*/*H*-location for the velocity profiles is measured from the second fence in the windward direction. While some differences can be seen, particularly near the fence, the profiles show good agreement. Close to the second fence, the velocity is reduced due to the effect of the first fence, e.g., above z/H = 1.0 at x/H = 0, 1, and 3. By about x/H = 6, the effect of the first fence on the velocity is small and the two fences produce results similar to a single fence. These results confirm prior observations that closely spaced rows of vegetation act essentially as a single fence. When the spacing between fences increases, the first fence exerts a stronger influence on the flow field behind the second fence, as demonstrated in Figure 29, for spacings of 5*H* and 10*H*. A greater reduction in velocity is seen above z/H = 1.0 near the fence and the influence of this low velocity extends further downwind. At x/H = 18, the effects on the velocity profile are still seen and do not diminish until about x/H = 25~30. Based on these results, fences spaced greater than about 5*H* should be treated as two individual fences.

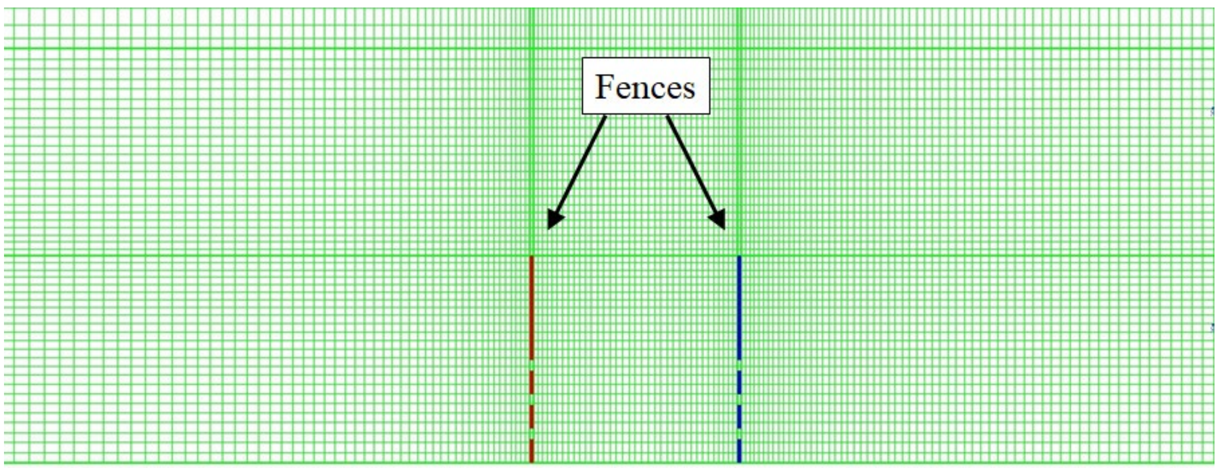


Figure 26. Diagram. Geometry and numerical mesh for two fences separated by a distance of H. Flow is from left to right.

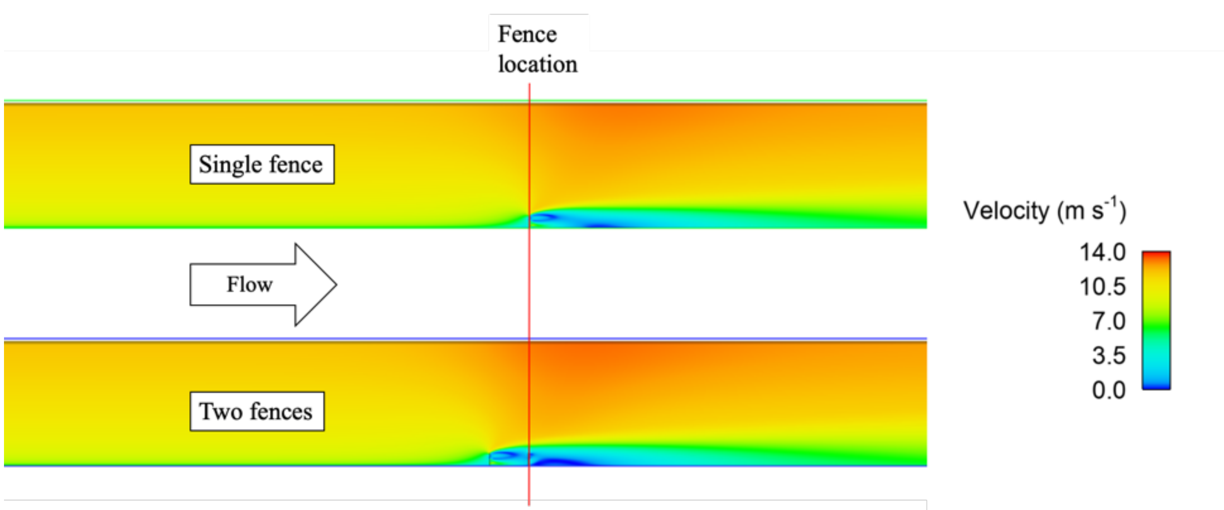


Figure 27. Diagram. Contours of velocity magnitude around a single fence and two fences separated by a distance of 3H. The red line shows the location of the second fence.

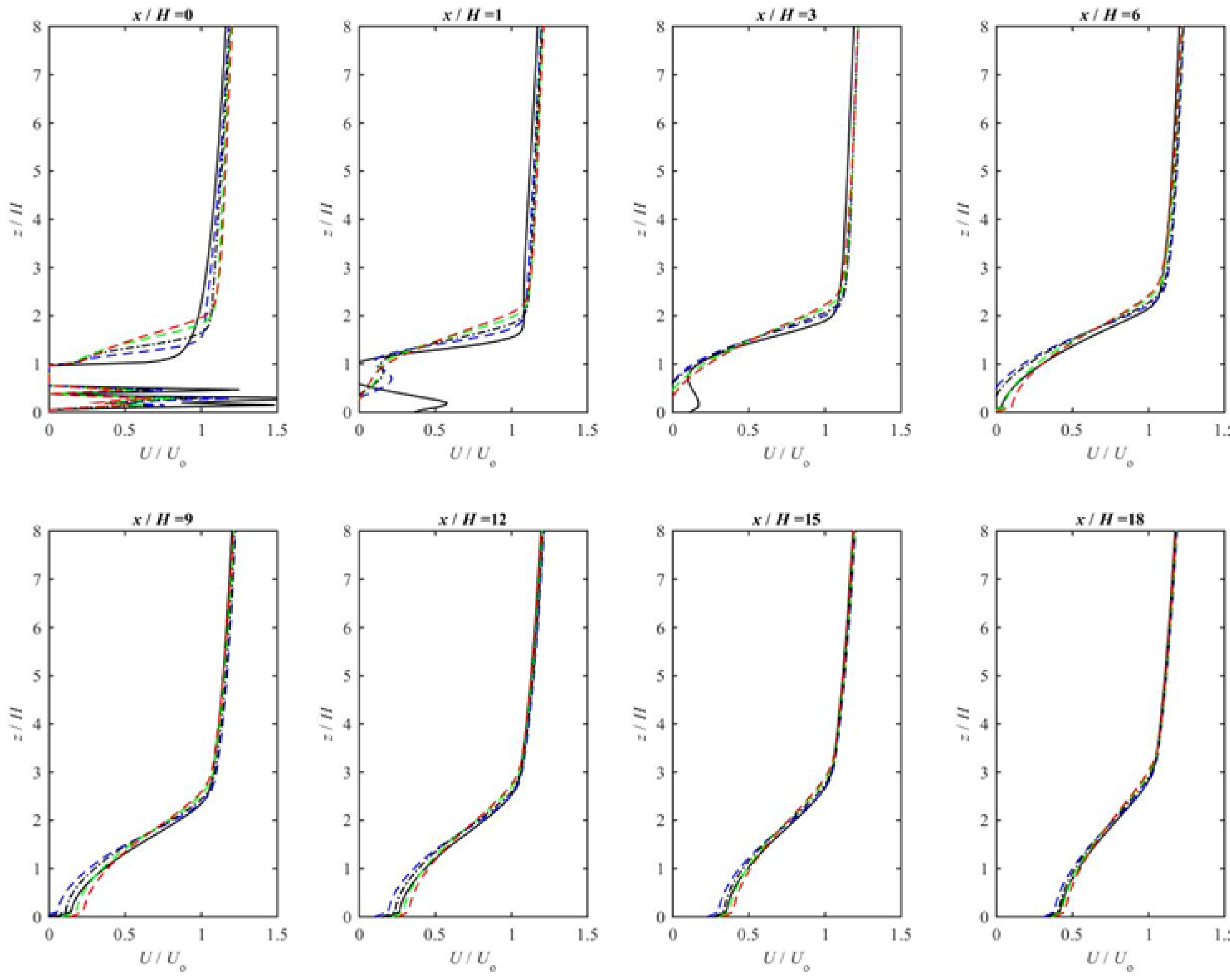


Figure 28. Diagram. Streamwise velocity profiles behind a single fence (solid black line) and two fences separated by a distance of 0.5*H* (dashed blue line), *H* (dash-dot black line), 2*H* (dashed green line), and 3*H* (dashed red line). For two fences, *x*/*H* specifies the distance behind the second fence.

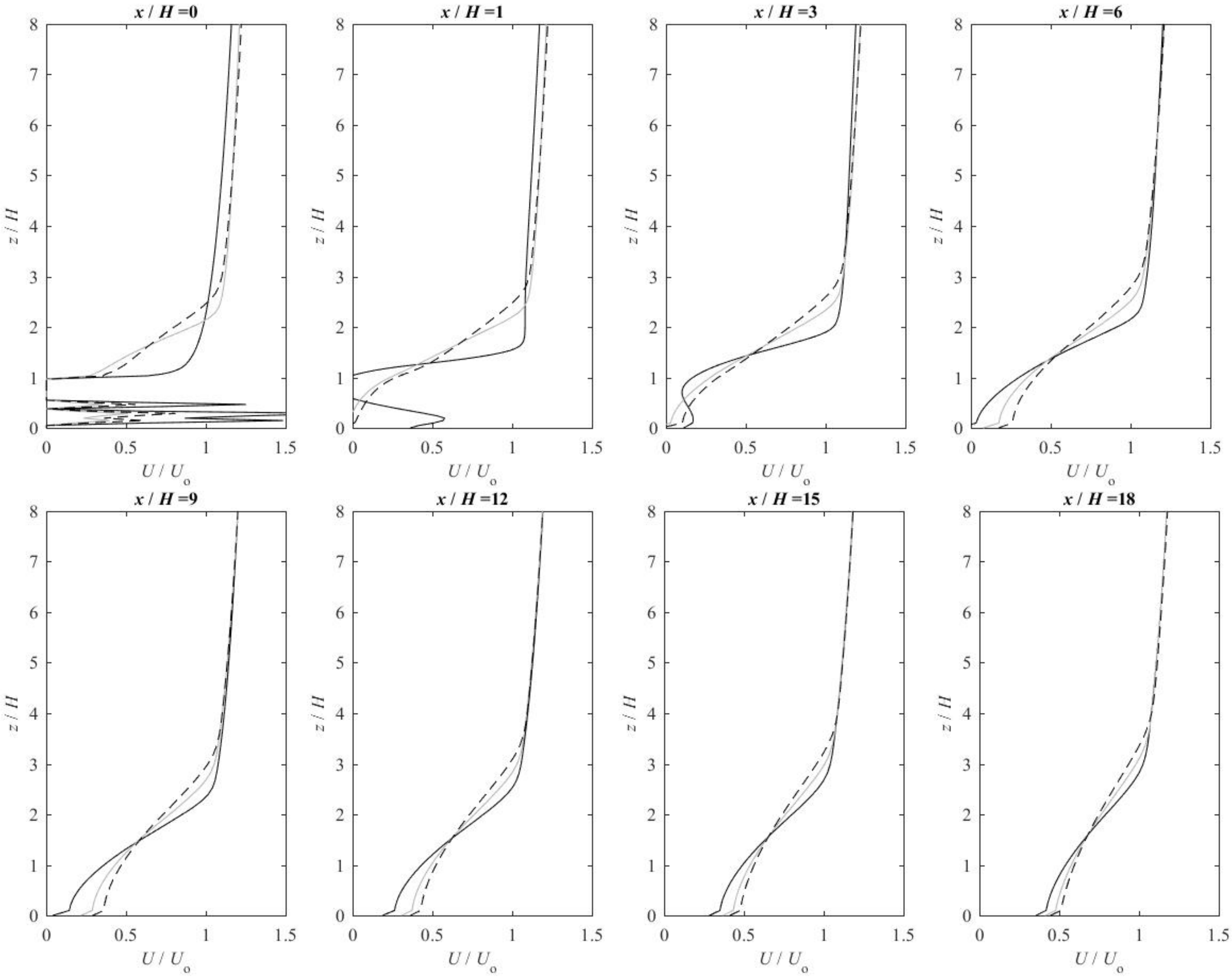


Figure 29. Diagram. Streamwise velocity profiles behind a single fence (solid black line) and two fences separated by a distance of 5*H* (solid grey line) and 10*H* (dashed black line). For two fences, *x*/*H* specifies the distance behind the second fence.

SIMULATIONS OF LIVING SNOW FENCES TO SUPPORT DESIGN

To aid in the design of LSFs, a series of simulations were performed for a variety of aerodynamic conditions and fence characteristics. Flow around a fence scales with fence height, meaning that a constant height of 1.0 m (3.3 ft) could be used in all simulations. The values of fence porosity included P = 0%, 30%, 40%, 50%, and 60% and average velocity included U_o = 10, 15, 20, 25, and 30 m/s (22, 34, 45, 56, and 67 mph). These simulation parameters resulted in the Reynolds number based on fence height ranging from $R_{eH} = 7.6 \times 10^5$ to 2.3×10^6. In the results shown below, the average velocity is indicated using a notation for Reynolds number. For example, Re_1 corresponds to a wind velocity of 22 mph, Re_2 to 34 mph, etc. These simulations used similar numerical settings as the validation case described above, including the same domain (relative to fence height), meshing strategy, boundary conditions, turbulence model, and convergence criteria. Combining all porosity and mean velocity values resulted in 25 simulations.

Figures 30 and 31 summarize the streamwise velocity profiles for these simulations. The profiles have been normalized using the fence height and the average velocity. Profiles are reported for various normalized locations, *x*/*H*, downwind of the fence. As with the validation case, the fence is located at *x* = 0. In Figure 30, velocity profiles are reported for all Reynolds numbers (all average velocities) for a fence with a porosity of 30%. The normalized results collapse to a single line for all locations. Similar findings were observed for all other porosity values. This result is not uncommon for highly turbulent flows and indicates a similar behavior for all wind speeds. Figure 31 shows velocity profiles for all porosity values at a constant velocity of 22 mph (Re_1). The results show that as porosity increases, the velocity behind the fence also increases. This is because higher porosity fences contain more void space and, therefore, less vegetation to impede the air flow. A notable feature of the solid fence (*P* = 0%) is the presence of negative velocity values behind the fence, indicating the presence of a recirculation region. This region is not present in porous fences, where all flow behind the fence is in the downwind direction. The trends demonstrated in Figure 31 were observed for all other average velocities.

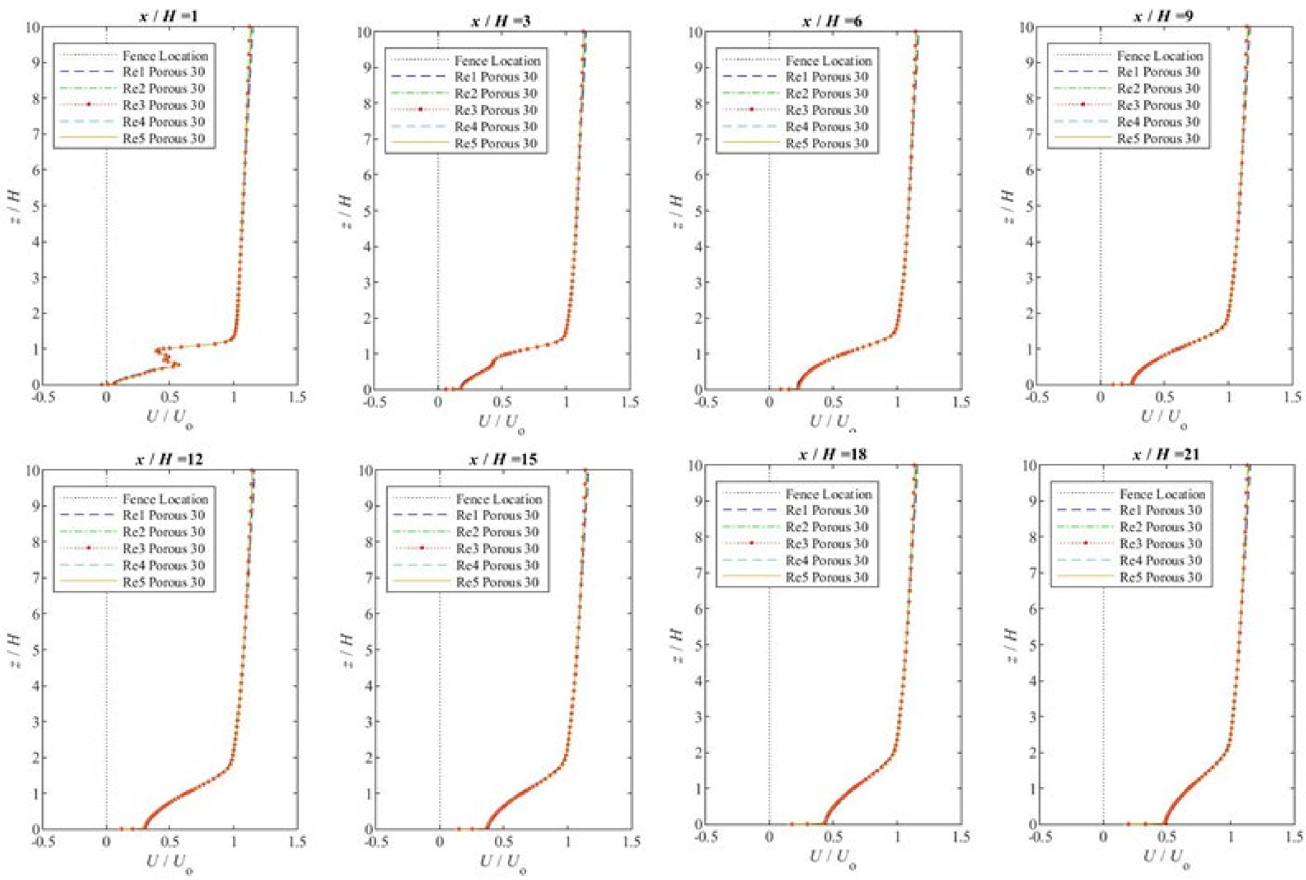


Figure 30. Diagram. Streamwise velocity profiles from the numerical simulations for all Reynolds numbers and a porosity of 30%.

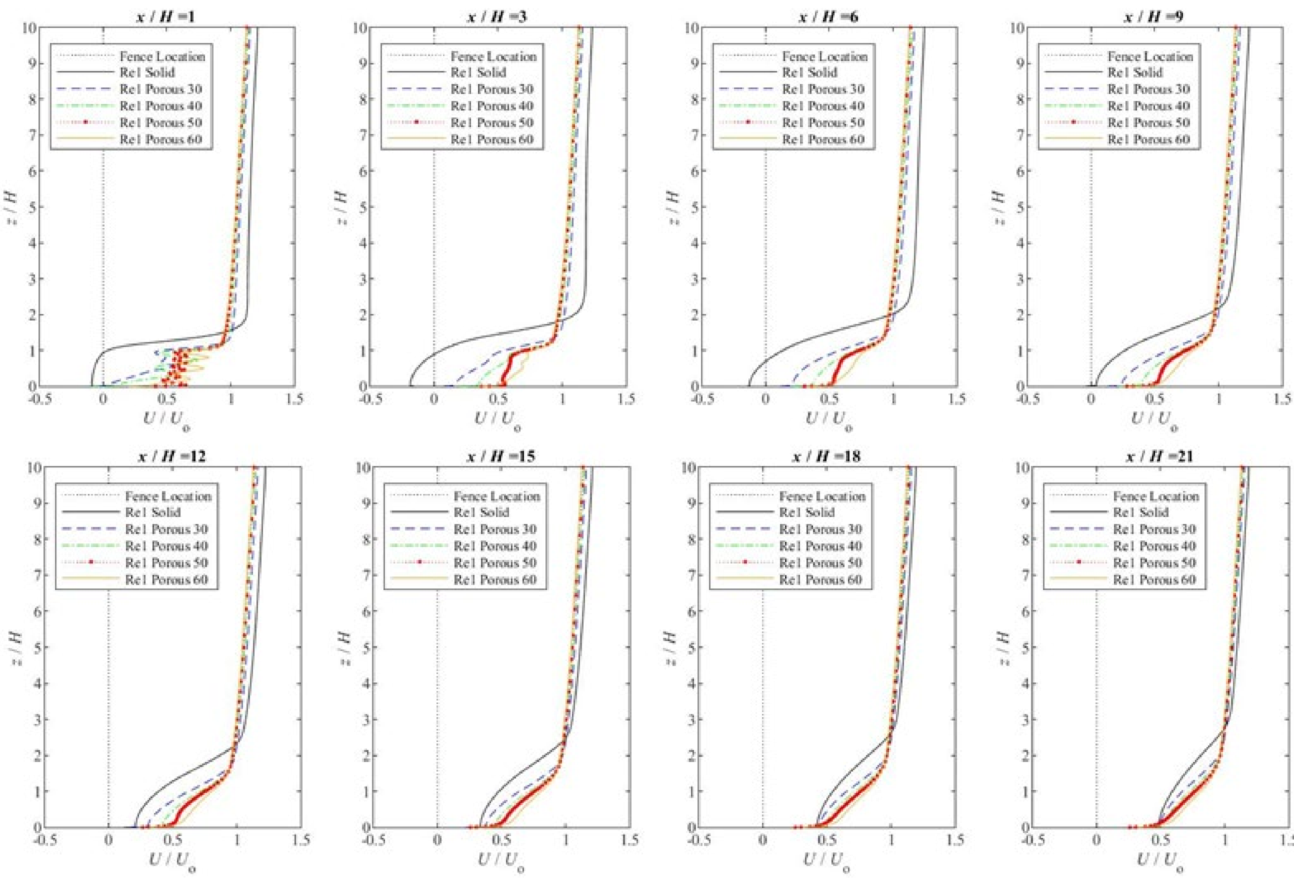


Figure 31. Diagram. Streamwise velocity profiles from the numerical simulations for Re_1 (U_o = 22 mph) and all porosity values.

CFD model results were used to identify the length of the expected region of snow deposition downwind from the fence. Snow transport is a complex process influenced by wind speed, turbulence, and other factors. Most studies identify the threshold for snow transport using either average wind velocity (e.g., Male, 1980; Li & Pomeroy, 1997) or shear velocity, also known as friction velocity (e.g., Bagnold, 1941; Sundsbo, 1996; Tominaga et al., 2011; Alhajraf, 2004). Shear velocity, u_*, is defined as the square root of the wall shear stress divided by fluid density. The wall shear stress is the force per unit area applied tangentially to the solid boundary by the airflow. A common value for the threshold of motion is u_* = 0.20 m/s (Bagnold, 1941; Sundsbo, 1996; Tominaga et al., 2011). For average wind velocity, Li & Pomeroy (1997) used field observations to identify a threshold velocity of about U_o = 10 m/s for air temperatures near 0°C. Using these two values, a nondimensional threshold is found by normalizing the shear velocity with the average wind velocity; then, the threshold for snow transport becomes u_*/U_o = 0.020. This normalized threshold was adopted here to define the extent of snow deposition downwind of the fence. Examples of normalized shear velocity are shown in Figure 32 for all porosity values at one average wind speed. Beyond the fence (x/H > 0), the shear velocity decreases as the wind speed decreases due to the influence of the fence. Further downwind, the shear velocity begins to increase and the flow recovers from the effects of the fence. Once the normalized shear velocity is larger than the threshold, $u_*/U_o = 0.020$, snow can be transported from the surface and deposition is unlikely. Therefore, the region of deposition is defined as the length downwind of the fence where $u_*/U_o \leq 0.020$. As seen in Figure 32, the length of the deposition region depends on the fence porosity. Similar trends were seen for other wind speeds.

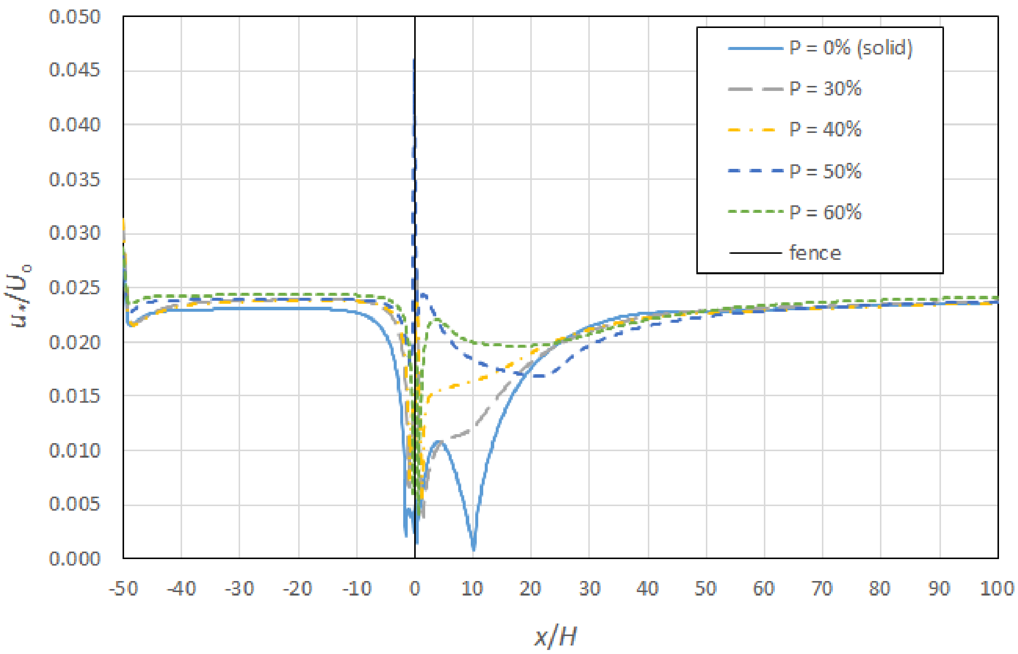


Figure 32. Diagram. Distribution of normalized shear velocity for *Re*$_3$ (U_o = 45 mph) and all porosity values. The fence is located at x/H = 0.

SIMULATIONS OF LIVING SNOW FENCES ON EMBANKMENTS

The preceding simulations are applicable to field situations where the terrain is relatively flat and can be considered valid when the slope is within 15° of horizontal. While many sites that can benefit from LSFs have flat terrain, embankments with slopes greater than 15° may also experience problems due to blown snow. To address these cases, simulations were performed for the embankment geometry shown in Figure 33. The fence height and location were varied relative to the embankment to aid in the development of design strategies. Additional simulations were performed using multiple fences on the embankment.

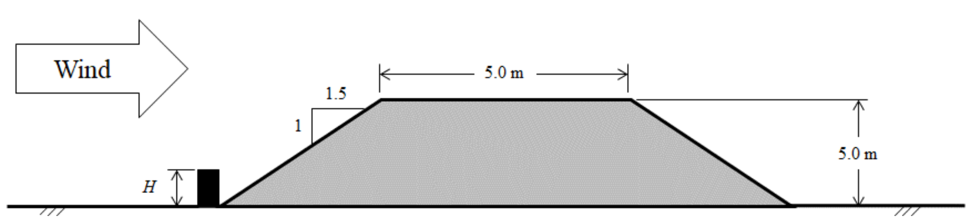


Figure 33. Diagram. Embankment geometry used in simulations with an example snow fence located at the base.

Figure 34 provides contours of velocity magnitude for various fence configurations on an embankment. The results in Figure 34 are for a single wind speed (Re_3) and fence porosity (P = 50%). When no fence is present, the flow moves unimpeded over the embankment. In this case, snow will be transported over the embankment where it can be deposited on the top surface, particularly if a guardrail is present. Fences placed near the base of the embankment promote deposition on the embankment; however, the region of deposition is smaller than that for the same fence on flat terrain. Placing fences on the embankment creates a region of deposition further up the slope. Multiple fences on the embankment encourage snow deposition over a larger region as the flow moves up the slope. These results demonstrate that appropriately placed fences can reduce the amount of snow available to deposit on the top surface of the embankment.

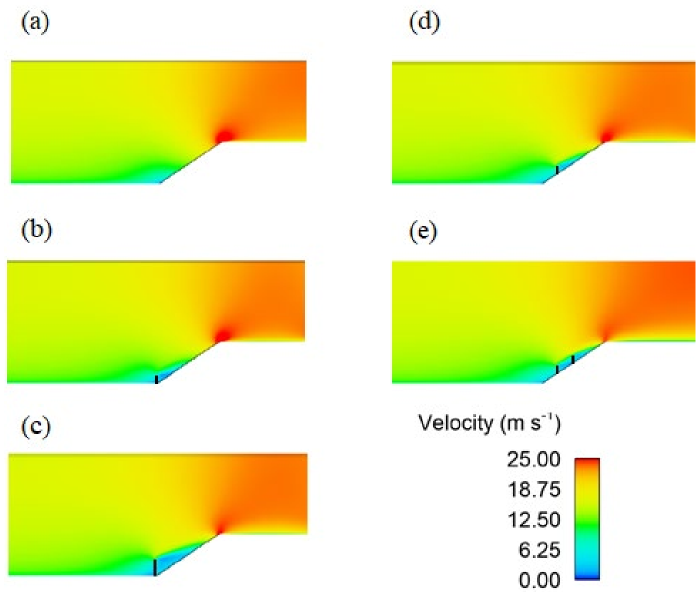


Figure 34. Diagram. Contours of velocity magnitude for Re_3 (U_o = 45 mph) and P = 50% for (a) no fence, (b) one fence (H = 1.0 m) at the base of the embankment, (c) one fence (H = 2.0 m) at the base, (d) one fence (H = 1.0 m) on the embankment slope, and (d) two fences (H = 1.0 m) on the embankment slope.

Summary

A series of CFD simulations were completed to support the design of LSFs. The modeling approach was validated using laboratory data collected in a wind tunnel for flow around a fence with nonuniform porosity. Results of the validation simulations confirmed appropriate choices for boundary conditions, meshing strategy, turbulence model, and convergence criteria. A series of simulations were then run for a range of average wind speeds and fence porosity over flat terrain. The results of these simulations were used to estimate the region of snow deposition using a threshold shear velocity. For sites where the terrain cannot be considered flat, simulations were performed for an embankment with a variety of different fence configurations. The results of these simulations provide the basis for the design guidelines presented in Chapter 6.

CHAPTER 5: FIELD TESTING OF LIVING SNOW FENCES

Field testing of LSFs was conducted on the state of Illinois highway system to provide data for calibrating the numerical model developed in the study. The field test also served as a separate task to evaluate the effectiveness of LSFs in Illinois. This chapter documents all living snow fence field test activities, including site selection, site setup, site monitoring, data collection, and analysis.

SITE SELECTION

Several criteria were used to select living snow fence sites. The primary one is the accessibility and identifiability of the LSF sites. The problems with snow drifting and snow blowing are acute in large open areas along Illinois highways; therefore, the focus was given to road segments that are prone to problems with blowing snow along open lands. In addition, traffic volume, prevailing wind direction, diversity and maturity of vegetation, and topography were also considered. After several field inspections, seven LSF sites that meet the selection criteria were identified before the 2016–17 winter season for the field experimentation, as well as one control site next to I-80. Figure 35 shows the locations of the selected LSF sites. Table 4 presents the characteristics of the selected LSF sites.

Before the 2018–19 winter season, four control sites without LSFs close to four existing LSF locations (two I-39 sites and two I-72 sites) were identified for comparison to LSF sites at similar weather and traffic conditions. They are located on I-39, I-55, I-72, and I-74, respectively. The site on I-80 was abandoned for the winter 2018–19 observation period because of a lack of resources.

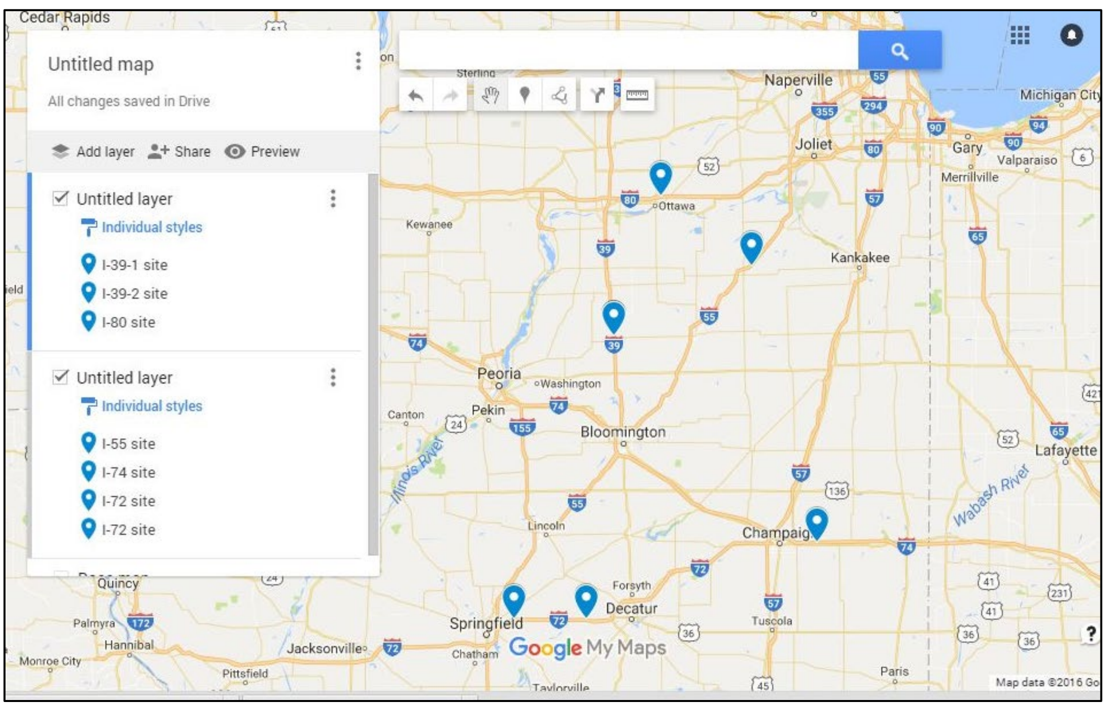


Figure 35. Picture. Geographic map of selected LSF sites.

Source: Google Maps

Table 4. Characteristics of Selected LSF Sites

Location	Species	Length (feet)	Width (feet)	Height (feet)	Porosity (%)
I-80 LaSalle	Mature Honeysuckle	360	20	18	N/A
I-55 Dwight	Grey Dogwood	220	25	20	55
I-39-1 Minonk	Indigo Bush	200	15	12	30
I-39-2 Minonk	Staghorn Sumac	200	14	13	35-45
I-74 St. Joseph	American Plum	200	30	20	45
I-72 Niantic	Washington Hawthorne	200	30	35	40
I-72 Dawson	Oak with Prairie Grass	200	30	40	40

SITE SETUP

The main data collected in the field test are the snow depth and trapped snow volume of each LSF site. Considering its reliability, easiness, and inexpensiveness, the traditional measuring stake method was employed to obtain the snow depth measurements in the field. This section summarizes the method used in the study to set up field sites.

Set Up Measurement Grids

Preliminary surveying was conducted to set up measurement grids for each LSF site. Considering its field condition, a 30–40 ft buffer zone to the edge of the pavement was left for each site. To catch the snow accumulation pattern along a snow fence, several rows of measurement points were identified on the downwind side of each snow fence, as well as one row of measurement points on the upwind side. Along the measuring rows, several columns of measurement points were identified, forming the measurement grids. The row spacing is 10 ft, while the column spacing is around 20 ft. To locate those measurement points in the field, the centerline of each snow fence site was identified first, then the row marks were marked on the ground. Following that, the column points on each row were identified using isosceles triangles stretched from the crossing point of the centerline and pavement edge. All the measurement grid points were permanently marked on the ground before the measurement stakes were setup.

Set Up Measuring Stakes

Solid steel rebars with a diameter of 0.5 in. and hollow stakes with a diameter of 1.5 in. were used for field measuring stakes. Before going to the field, the rebars and stakes were prepared in the lab. The rebars were cut 4 ft long and the stakes were cut 4 ft to 6 ft long. All stakes were painted with feet and inch marks. For easy readability in the field, a different color scheme was used to identify 1 to 6 ft (Figure 36).

To set up measuring stakes in the field, short rebars were inserted into the ground on each marked measurement grid point; painted hollow stakes were then put onto the rebars (Figure 37). This way, all field measurements will start from ground zero and can be compared from site to site. Considering the general snow accumulation pattern, 4 ft stakes were set up along the rows next to the pavement edge, 8 ft stakes near the snow fences, and 6 ft stakes in between. Figure 38 shows the measuring stakes at the I-72 Niantic site.

Figure 36. Photo. Sample painted measuring stakes.

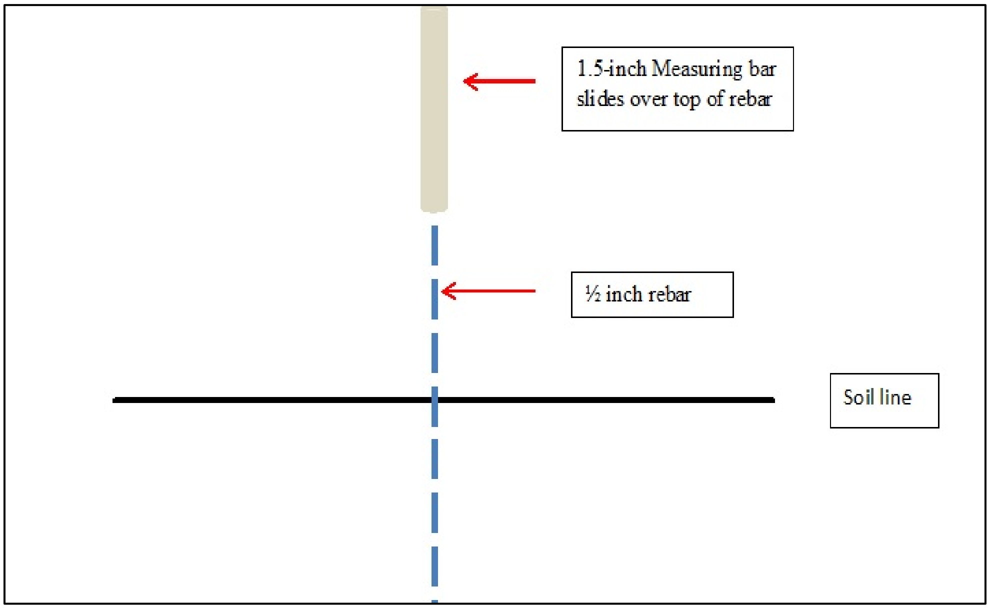


Figure 37. Diagram. Concept of rebars and stakes.

Figure 38. Photo. Measurement grid site at I-72 Niantic site.

SITE SURVEYING

After the measurement grids were set up, each site was surveyed before the winter season monitoring. Total stations were used to measure the elevation and relative position of each measurement grid point on the ground for each site. The data were entered into AutoCAD to depict the surface profile of each field site. After the control sites were selected before the 2018–19 season, they were also surveyed using the same method. Their surface profiles were illustrated using the AutoCAD tool.

SITE MONITORING

Each site was monitored closely during two consecutive winter seasons (2017–18 and 2018–19) to determine if field data collection is needed. Data collection was initiated if the following weather forecast criteria were met:

- Weather forecast for 2 in. of snowfall or more.
- Projected wind speed more than 5 miles per hour.
- Expected temperature less than 30°F.

DATA COLLECTION AND ARCHIVE

Before and after a snow event, the snow depth at each measuring stake point was collected and entered into a form prepared using Excel. In the case of a heavy snow event, a high-definition spotting scope mounted on a windshield was used to help gather the snow depth data inside a vehicle parked along the roadside. Pictures and videos were taken at each data collection event for record. Pavement and air temperatures, wind speed, and prevailing wind direction were also measured at each test location.

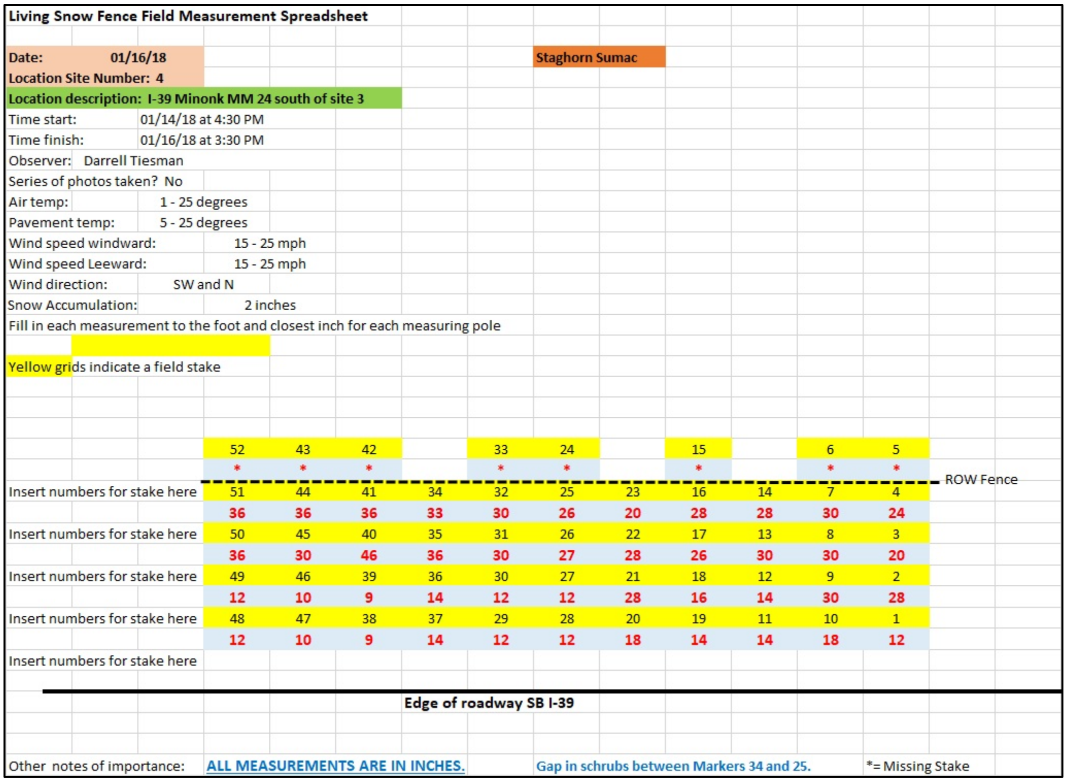
The raw data was converted into a digital format after collection. The snow volume accumulated in each LSF site was calculated from the grid dimension and snow depth using the cross-section method for earth volume calculation using the average end area formula $V = 0.5 \times L \times (A1 + A2)$, where $A1$ and $A2$ are the end areas and L is the distance between two end areas.

RESULTS AND DISCUSSION

The project was originally supposed to end after the 2017–18 winter season. Because of a mild 2017–18 winter, only a few snowstorm events that met the minimum requirements were observed. Therefore, the project was extended to cover the 2018–19 winter season. This section presents the collected snow depth data as well as the calculated accumulated snow volumes for both the 2017–18 and 2018–19 winter seasons.

Snow Depth Measurements

A few snow events were observed during the 2017–18 and 2018–19 winter seasons at test sites. Figure 39 presents one example of the snow depth data collected from the I-39 (2) site at Minonk after the snow event on January 14, 2018. Note that the field snow-depth measurements are much higher than the depth of snow precipitation. Besides the snow trapped by LSFs, the natural plantings (grass) in the field also contributed to the high snow-depth measurements. Because the trapped snow was calculated using the difference of snow depths before and after each snowstorm, the grass would have little impact on the results. Grass also helps trap snow in the field, so it is beneficial to leave the grass in the field. However, for ease of field measurement collection and to test the effectiveness of LSFs solely, all test sites were mowed before the 2018–19 winter season. Figure 39 presents snow-depth measurements taken at the I-39 (I) site at Minonk on January 10, 2019. The field measurement for all sites during the two winter seasons are presented in Appendix C.



Living Snow Fence Field Measurement Spreadsheet

Date: 01/16/18 | Staghorn Sumac
Location Site Number: 4
Location description: I-39 Minonk MM 24 south of site 3
Time start: 01/14/18 at 4:30 PM
Time finish: 01/16/18 at 3:30 PM
Observer: Darrell Tiesman
Series of photos taken? No
Air temp: 1 - 25 degrees
Pavement temp: 5 - 25 degrees
Wind speed windward: 15 - 25 mph
Wind speed Leeward: 15 - 25 mph
Wind direction: SW and N
Snow Accumulation: 2 inches
Fill in each measurement to the foot and closest inch for each measuring pole

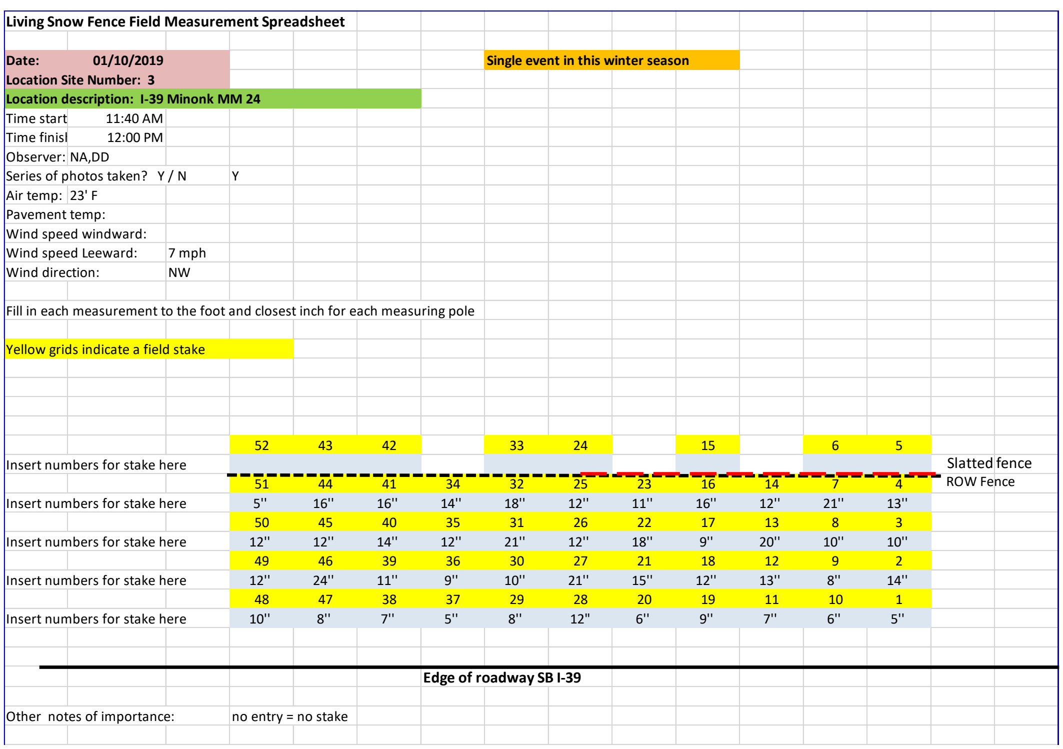
Yellow grids indicate a field stake

	52	43	42		33	24		15		6	5	
	*	*	*		*	*		*		*	*	ROW Fence
Insert numbers for stake here	51	44	41	34	32	25	23	16	14	7	4	
	36	36	36	33	30	26	20	28	28	30	24	
Insert numbers for stake here	50	45	40	35	31	26	22	17	13	8	3	
	36	30	46	36	30	27	28	26	30	30	20	
Insert numbers for stake here	49	46	39	36	30	27	21	18	12	9	2	
	12	10	9	14	12	12	28	16	14	30	28	
Insert numbers for stake here	48	47	38	37	29	28	20	19	11	10	1	
	12	10	9	14	12	12	18	14	14	18	12	
Insert numbers for stake here												

Edge of roadway SB I-39

Other notes of importance: ALL MEASUREMENTS ARE IN INCHES. Gap in schrubs between Markers 34 and 25. *= Missing Stake

Figure 39. Chart. Collected data at test site I-39 (2) at Minonk.



Living Snow Fence Field Measurement Spreadsheet

Date: 01/10/2019 | Single event in this winter season
Location Site Number: 3
Location description: I-39 Minonk MM 24
Time start 11:40 AM
Time finisl 12:00 PM
Observer: NA,DD
Series of photos taken? Y / N Y
Air temp: 23' F
Pavement temp:
Wind speed windward:
Wind speed Leeward: 7 mph
Wind direction: NW

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	52	43	42		33	24		15		6	5	
Insert numbers for stake here												Slatted fence
	51	44	41	34	32	25	23	16	14	7	4	ROW Fence
Insert numbers for stake here	5''	16''	16''	14''	18''	12''	11''	16''	12''	21''	13''	
	50	45	40	35	31	26	22	17	13	8	3	
Insert numbers for stake here	12''	12''	14''	12''	21''	12''	18''	9''	20''	10''	10''	
	49	46	39	36	30	27	21	18	12	9	2	
Insert numbers for stake here	12''	24''	11''	9''	10''	21''	15''	12''	13''	8''	14''	
	48	47	38	37	29	28	20	19	11	10	1	
Insert numbers for stake here	10''	8''	7''	5''	8''	12''	6''	9''	7''	6''	5''	

Edge of roadway SB I-39

Other notes of importance: no entry = no stake

Figure 40. Chart. Collected data at test site I-39 (1) at Minonk on January 10, 2019.

The field measurement data shows the snow depth was comparatively higher along the stakes right behind the LSF location and decreased with the increase in distance from the LSF towards the edge of the roadway. Similar patterns were observed at other LSF sites. Those patterns indicate that a large portion of the wind-transported snow has been deposited immediately behind the snow fence.

Trapped Snow Volumes

This subsection presents the calculated accumulated snow volumes based on the collected snow depth data for the 2017–18 and 2018–19 winter seasons. The trapped snow volumes of LSFs were compared to those in their control sites.

Winter 2017–18

Table 5 presents snow volumes accumulated behind the living snow fence at each test site for snow events observed during winter 2017–18. With a similar site area, accumulated snow volume varies across sites due to different severity of snowstorms and the snow fence alignment/species. For the same snow event with similar snow precipitation on January 14, 2018, the I-80 site trapped more snow than the I-55 site. This is because the I-80 site is located on the north side of the east-west I-80, which stands perpendicular to the wind path to break the wind. The I-55 site is on the west side of the southwest-northeast I-55; the oblique angle formed between the snow fence and wind direction reduced the effectiveness of snow fences. The species would not be a contributing factor because the heights of two fences are similar (18 ft for I-80 vs. 20 ft for I-55).

Table 5. Calculated Snow Volume of Selected LSF Sites for Winter 2017–18.

Location	Species/Vegetation Type	Snow Event (Date)	Calculated Snow Volume (cubic feet)
I-80 LaSalle	Mature Honeysuckle	01/14/2018–01/16/2018	2275
I-55 Dwight	Grey Dogwood	01/14/2018–01/16/2018	1667
I-39-1 Minonk	Indigo Bush	01/14/2018–01/16/2018	1466
I-39-2 Minonk	Staghorn Sumac	01/14/2018–01/16/2018	1320
I-74 St. Joseph	American Plum	01/04/2018–01/05/2018	833
I-72 Niantic	Washington Hawthorne	01/14/2018–01/16/2018	750
I-72 Dawson	Oak with Prairie Grass	12/29/2017–12/30/2017	600

Winter 2018–19

More snowstorms were recorded during the 2018–19 winter season than the 2017–18 season. However, only data collected on I-55, I-72, and I-74 sites were used for the analysis because of the lack of before or after snow-event measurements. Table 6 presents snow volumes accumulated behind the living snow fence for test sites and their control sites for snow events observed during winter 2018–19. The results show that the snow trapped at living snow fence sites was generally more than that at sites with no snow fences.

Table 6. Calculated Snow Volume of Selected LSF Sites.

Site	Snow Event No.	Date (Before Snowfall–After Snowfall)	Snow Volume (ft³)	Control site Snow Volume(ft³)
I-55 MM222	1	01/10/2019–Unknown	867	942
	2	01/18/2019–01/20/2019	2475	2422
	3	01/25/2019–01/29/2020	4017	1887
I-74 MM193	1	01/10/2019–01/14/2019	3025	2305
	2	01/18/2019–01/20/2019	4008	1346
I-72 MM110	1	01/10/2019–01/13/2019	4375	3789
I-72 MM 127	1	01/10/2019–01/13/2021	4467	4170

Discussion

The field snow-depth measurements and trapped snow volume results have evidenced that a large portion of blowing snow deposited immediately behind the snow fences and snow fenced sites have trapped significantly higher volumes of snow than non-snow-fenced sites. The field experiment findings indicate that the tested snow fences in Illinois are effective in reducing blowing snow onto roadways. This is an important point, given that the snow fences tested are all within the ROW boundaries of Illinois freeways (100–120 ft). Previous studies suggest snow fences be located at least 35*H* or more than 200 ft from the roadways to be effective (Blanken, 2009; Heavy & Volk, 2014). Usually, those locations are on private land beyond roadway ROW. As indicated in the study, living snow fences located within the Illinois freeway ROW are effective in trapping snow and reducing snow blowing. Although LSF effectiveness still needs to be verified further, living snow fences within ROW could still be beneficial to agencies.

Past studies that suggested long setback distances of snow fences from the edge of roadway were conducted in Minnesota, Wyoming, or New York. Those northern states often experience severe snowstorms, high-speed winds/gusts, and heavy snow precipitation during winter. Winters in Illinois are relatively mild in comparison, especially in central Illinois (where the I-72 sites were located). A long setback distance of 35*H* or over 200 ft is appropriate for addressing the snow blowing and drifting issues in northern states but may not be necessary for Illinois or states at similar latitudes or with similar winter weather. Using a snow-trapping function model by key structural variables, Heavey (2013) showed that when capacity/transport ratio exceeds 15:1, living snow fence setback distance can be 10 m or less, which is much smaller than what is recommended in the literature and setback distances observed in the field. The findings from the study evidenced this point.

One concern of inadequate setback distance of snow fence from the roadway is that snow may deposit on the roadway. Looking into the field measurement data, snow depth measured along the row closest to the roadway edge was generally below or around 10 in. Considering the typical gap between the last row and roadway edge of 30 to 40 ft and the roadway embankment, it is unlikely that high-volume snow was deposited on roadways.

SUMMARY

A field experiment was conducted on seven selected locations in Illinois to investigate the effectiveness of existing living snow fences and provide data for calibrating the numerical model. After the site selection, measurement grids were formed, and stakes were put into rows and columns at each site to measure the snow depths to catch the snow deposition pattern and to determine the potential of LSF to capture snow. The test sites were monitored over two winter seasons and several snow events were recorded for each winter. Volumes of snow deposited at snow fence sites were calculated and two-sample student t-tests were conducted to compare them with those from their controls (adjacent highway segments without any fence).

From the data collected, snow deposition was generally higher immediately behind the snow fence barrier and decreased gradually with the increase in distance from the snow fence toward the roadway. The trapped snow volume calculated showed higher snow deposition volumes of fenced sites than their controls. Despite not having a long setback distance from the roadway, as suggested by past studies, the tested LSFs in Illinois that are within a ROW were effective in trapping blowing snow. No evidence showed that high-volume snow was deposited on the roadway at those sites. This finding reveals that the proper snow fence setback distance should consider the local prevailing winter weather conditions, and snow fences within ROW can still be beneficial to agencies.

CHAPTER 6: USING THE MODEL TO AID DESIGN OF LIVING SANOW FENCES

The results of the CFD simulations are compiled here in the form of design guidelines for LSFs. These guidelines are presented for siting LSFs on flat terrain and those with mild slopes (< 15° from horizontal). Guidance is provided for determining fence setback, wind characteristics, fence orientation, as well as fence height and porosity. Fences comprised of multiple rows, such as standing rows of corn, are also addressed. For sites with embankments with steeper slopes, guidelines are provided that include a fence at the base and one or more fences on the embankment.

The CFD simulations provide an estimate of the length of the region where snow deposition is expected as a function of fence characteristics. The design procedure uses the available right-of-way at a site to determine the appropriate fence characteristics (e.g., height and porosity) to prevent snow deposition on the road. This approach of using the available length for deposition to determine the fence characteristics differs from prior snow fence design procedures (Tabler, 2003; Heavey & Volk, 2013). Past procedures estimate the total snow transport during a season and determine the fence characteristics and setback required to store snow away from the road for an entire season. While these designs have been effective, the resulting setback may be difficult to achieve at sites with limited right-of-way. The procedure presented here provides an alternative that uses available setback to design the fence. This approach does not consider the snow transport over an entire season and may be less effective in years with several large snowfall events, very large single events, or a sequence of small events with little snowmelt in between. However, this procedure is expected to be effective for more frequent snowfall events and multiple freeze/thaw cycles such as the conditions that occurred over the field-monitoring period.

ELEMENTS OF LSF DESIGN

The key elements of an LSF design include fence orientation, setback, and selecting a species for the fence. The setback is the perpendicular distance from the location of the downwind end of the fence to the edge of the roadway, as shown in Figure 41. The setback represents the length available for snow deposition. The species or group of species that comprise the fence control the fence height and porosity. The orientation of an LSF refers to the longitudinal alignment of the fence relative to the prevailing wind direction. Fence orientation is quantified by the angle of attack relative to the fence α, shown in Figure 41, defined as the angle between the wind direction and the alignment of the fence. For example, if α = 90°, then the wind direction is perpendicular to the fence, and if α = 0°, then the wind direction is parallel to the fence. An angle of attack can also be defined by the wind direction relative to the road alignment α_r. If the fence and road are parallel, as in Figure 41, the two angles of attack are equal ($\alpha = \alpha_r$).

LSFs are commonly aligned parallel to the roadway to minimize the amount of vegetation and land required for the fence. For this reason, LSFs perform best when the angle of attack is close to perpendicular. Experience has shown that within 35° of perpendicular, or α > 55°, is acceptable for design (Tabler, 2003). As the angle of attack decreases, the effectiveness of the LSF will also decrease. For this reason, LSFs are not recommended if the angle of attack relative to the road is much less than 55°.

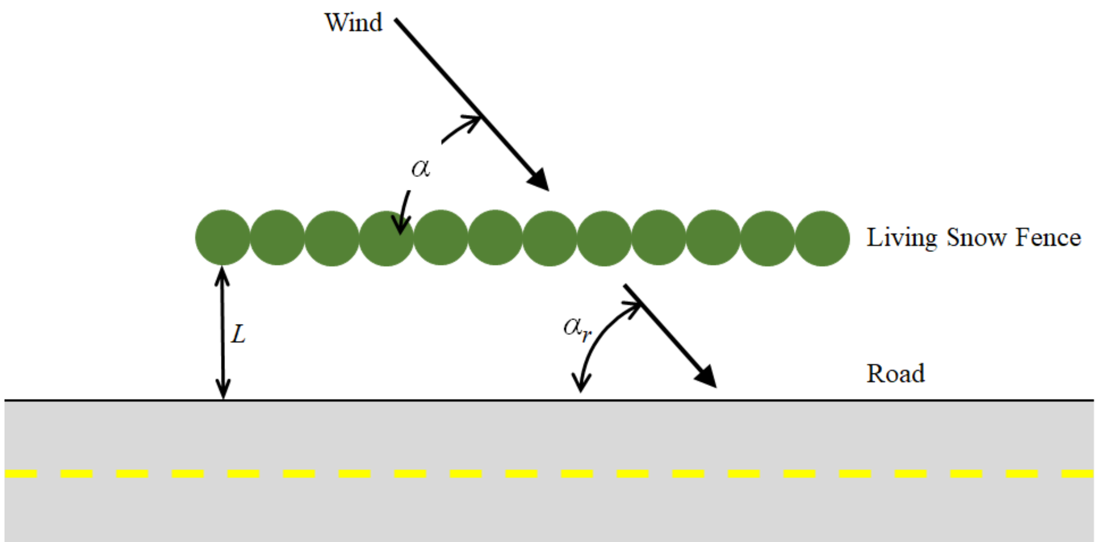


Figure 41. Diagram. Plan view of an LSF demonstrating the setback (*L*) and angle of attack relative to the fence (α) and relative to the road (α_r).

DESIGN GUIDELINES FOR FLAT TERRAIN

This procedure is intended for the design of LSFs on flat terrain or terrain with a longitudinal slope less than 15° from horizontal (upward or downward). The procedure can also be used for fences on an embankment when the longitudinal fence direction is oriented up the embankment slope. The fence characteristics are determined with the goal of maximizing the available storage while preventing snow deposition on the road. A spreadsheet is available in Appendix H to assist with the procedure.

Step 1: Determine Maximum Setback

The maximum setback, *L*, is the perpendicular distance from the location of the downwind end of the fence to the edge of the roadway. The setback at a site can be estimated using a topographic map or GIS. For sites where the fence is approximately parallel to the road, the setback distance will be constant. For sites where the fence is at an angle to the road, the minimum distance between the fence and the road should be used to ensure sufficient storage. For design calculations, it is recommended to use a value less than the maximum setback, e.g., 90–95% of maximum, to provide a factor of safety for the design.

Step 2: Estimate Wind Characteristics

For the site of interest, determine the design wind speed, *U*, and the prevailing wind direction. The design wind speed can be an average or representative wind speed for blown snow conditions and can be estimated from historical data or measured in the field. Similarly, the prevailing wind direction can be estimated from local meteorological data or measured in the field. Once the prevailing wind direction is known, the angle of attack relative to the road is determined with the aid of a map or GIS. If this angle is greater than 55°, an LSF aligned parallel to the road is appropriate. In this case, the prevailing wind direction is within 35° of being perpendicular to the road orientation. If the angle of attack relative to the road is less than 55°, an LSF will be less effective and alternative blown snow control measures should be considered. Figure 42 summarizes the effect of angle of attack on fence orientation.

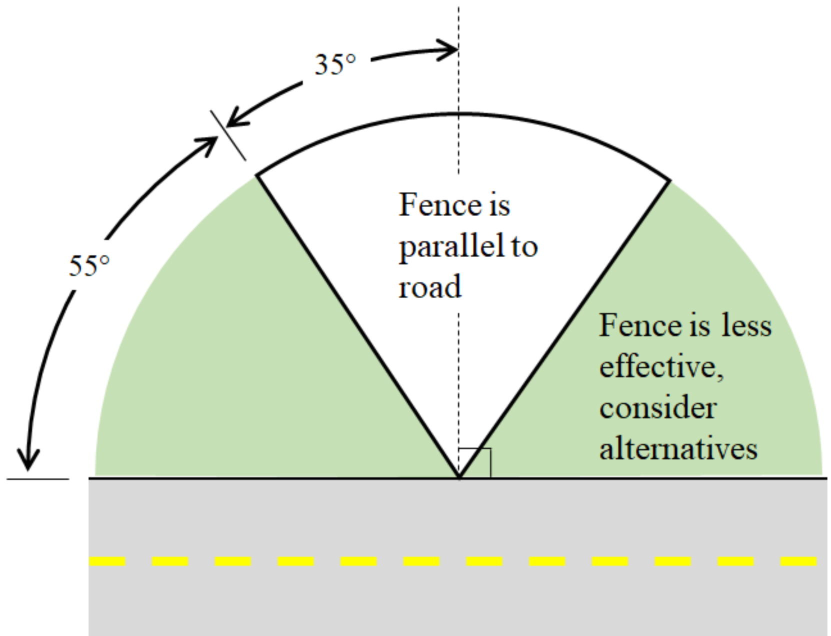


Figure 42. Diagram. Illustration of the effect of the angle between the prevailing wind direction and road on fence orientation.

Step 3: Estimate Fence Porosity

The porosity of an LSF is dependent on the species or group of species selected for the fence. The estimate in this step can be based on a desired species found in Appendix E in this report. Porosity of vegetation is a difficult parameter to quantify. For this reason, approximate values are sufficient for this step. Alternatively, one can take digital photos and then use them to estimate the porosity of LSF, following the methodology detailed in Appendix D (which is also incorporated into the design spreadsheet tool).

Step 4: Calculate Initial Fence Height

The required height of the fence is a function of the setback, wind speed, and fence porosity. Figure 43 provides the relation between these parameters. The setback to fence height ratio *L*/*H* is presented as a function of the design wind speed (horizontal axis) and porosity (curves). The procedure to determine the ratio *L*/*H* is illustrated with arrows on the figure. The fence height can then be calculated directly from this ratio, *H* = *L*/(*L/H*). Interpolation can be used for porosity values in between those shown in the figure. A porosity of 0% (solid wall) is shown in Figure 43 for reference only and is not recommended for design purposes.

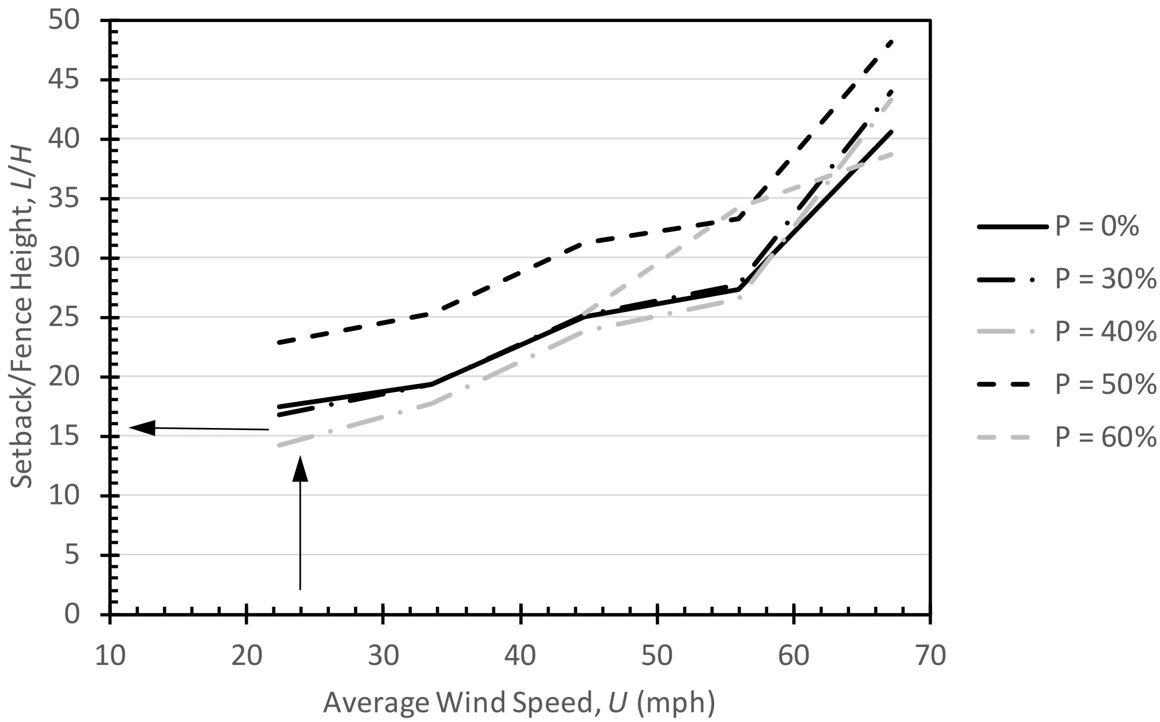


Figure 43. Chart. The ratio of setback to fence height as a function of wind speed for values of porosity.

Step 5: Select and Confirm Species for the Fence

Using the estimated porosity and calculated fence height (steps 3 and 4), select a species or group of species that best match these values, using Appendix E, which is also incorporated into the design spreadsheet tool. If a species that matches these values is not available, return to step 3 with a new estimate of porosity and repeat steps 3 and 4 until a suitable species or group of species is found. The fence height used for species selection should be considered a target value. Given the natural variability of vegetation, a uniform fence height is not possible. A fence that is shorter or taller than the target along its length is expected to have similar performance to the target fence height.

DESIGN EXAMPLE FOR FLAT TERRAIN

To demonstrate the design procedure, consider a site with 150 ft of available right-of-way and a design wind speed of 30 mph. The design wind direction can be considered perpendicular to the road orientation. The calculations for this example are also demonstrated on the spreadsheet provided in Appendix H.

- Step 1: Available setback, L = 150 ft
- Step 2: Design wind speed, U = 30 mph
- Step 3: Fence porosity, P = 50% (recommended initial estimate)
- Step 4: Calculate initial fence height, H

  From Figure 43 with U = 30 mph, L/H = 25

  Initial fence height, $H = L/(L/H)$ = (150 ft)/25 = 6.0 ft
- Step 5: Select and confirm species for fence

  The design calculations indicate that a fence with a mature height of about 6 ft and porosity of 50% is appropriate for this site. Potential species for LSFs are listed in Appendix E. *Illinois Rose* meets these requirements with a mature height ranging from 5.0 to 8.0 ft and a mature porosity of 50%.

EFFECT OF MULTIPLE ROWS

The CFD results in Chapter 4 indicate that fences comprised of closely spaced rows of vegetation (<5H) act essentially as a single-row fence with the same porosity. This finding indicates that the CFD results (e.g., Figure 43) and design procedure can be applied to multiple row fences where the setback is measured from the row closest to the road. In this case, the effect of multiple rows is generally a reduction in fence porosity. The porosity value used in step 3 of the design procedure is a representative value for the entire fence, not the value for a single row. Standing rows of corn is an example of a fence with closely spaced rows. Corn plants typically reach a height of over 5 ft and row spacing is usually less than 3 ft. These plantings result in a row spacing much less than the fence height, well below the requirement of row spacing less than five fence heights (<5H). The length of the deposition region produced by corn rows can be estimated with Figure 43 using estimates of the height of the rows and porosity. The design procedure does not apply to fences with larger row spacing (>5H). Such fences are not recommended because of the additional land required.

DESIGN GUIDELINES FOR EMBANKMENTS

These guidelines are intended for LSFs that protect roads on top of embankments such as at bridge crossings. Embankments are generally steeper than the 15° required by the procedure for flat terrain. The procedure presented here can be applied to embankments with slopes up to 34° or 1.5:1 (horizontal: vertical). The most effective configuration to reduce blown snow over embankments consists of a row of vegetation at the base of the slope followed by one or more rows on the embankment. Similar to the procedure for flat terrain, the goal of this design is to encourage snow deposition on the embankment and prevent deposition on the road located on the top of the embankment.

Figure 44 illustrates the general fence configuration for an embankment. Three rows of vegetation are shown on the embankment slope for demonstration purposes. More or less rows could be present depending on the embankment geometry. The key parameters to determine are (1) the height of the LSF at the base H_b, (2) the height of the LSFs on the slope H_s, (3) the length from the base to the first LSF on the slope L_b, (4) the spacing between rows on the slope L_s, and (5) the distance between the last rows of vegetation and the top of the embankment L_n. The steps below illustrate the procedure to determine each parameter. A spreadsheet is available in Appendix H to assist with the procedure.

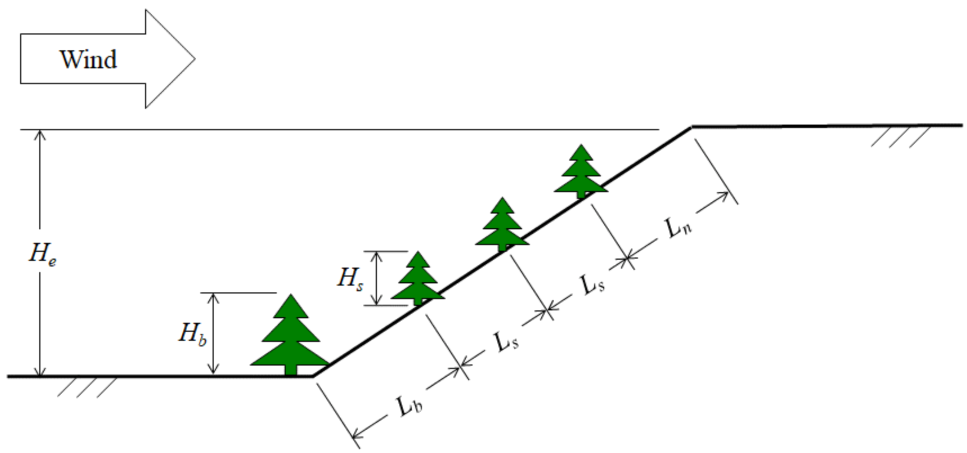


Figure 44. Diagram. Demonstration sketch for LSF configurations on an embankment with a slope up to 1.5:1 (horizontal: vertical).

Step 1: Select the Species for the Fence

The vegetation selected to comprise the LSFs are determined based on the fence height relative to the height of the embankment. Similar to the procedure for flat terrain, a fence porosity of about 50% is recommended. The height of the fence at the base of the embankment, H_b, is recommended to be a minimum of 20% of the total embankment height, H_e. A fence height of 40% will extend the deposition region more than $2H_b$ along the slope. For the fences placed on the embankment, a fence height H_s of about 20% of the total embankment height is recommended. Smaller fences can be used but with decreased storage capacity. Based on this recommendation, a species or group of species can be selected.

Step 2: Determine the Location for the First Row on the Embankment

The first row of vegetation on the embankment is located just beyond the deposition region of the fence at the base of the slope. This distance is determined from Figure 45 using the ratio of the height of the fence at the base, H_b, to the total embankment height, H_b / H_e. In Figure 45, the distance to the first row, L_b, is normalized by the height of the fence at the base. The distance L_b is measured parallel to the embankment slope (see Figure 44). The arrows on Figure 5 indicate the procedure.

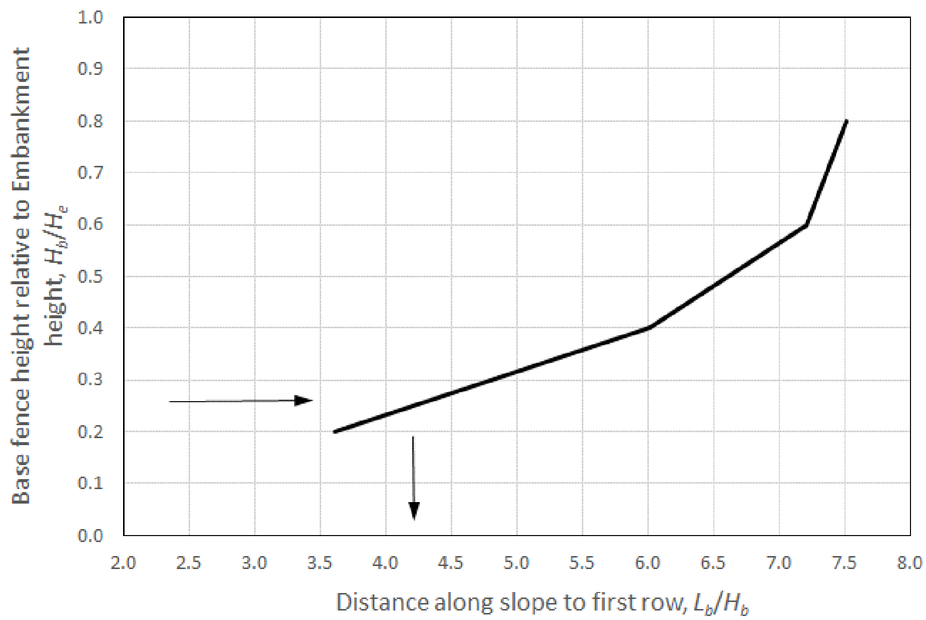


Figure 45. Chart. Relationship between the ratio of the height of the fence at the base to the embankment height and the location of the first row on the embankment.

Step 3: Determine the Spacing between Rows on the Embankment Slope

The numerical results indicate that a spacing of $L_s \approx 2H_s$, measured parallel to the slope, is an appropriate spacing between rows on the embankment. The number of rows on the embankment is determined by the embankment geometry, the spacing between rows L_s, and the distance between the last row of vegetation and the top of the embankment L_n (found in step 4).

Step 4: Determine the Distance between the Last Row and Top of the Embankment

The distance between the last row of vegetation and the top of the embankment L_n should be at least $3H_s$ ($L_n \geq 3H_s$). This spacing allows deposition on the embankment prior to the top surface and is measured parallel to the slope (see Figure 44).

Step 5: Finalize the Fence Configuration

Once steps 1–4 are complete, the species and the spacing between rows are known. The number of rows of vegetation on the embankment is based on the total length of embankment and the different distances determined in steps 2–4. Rows separated by a distance of L_s should begin a distance of L_b from the base and continue until the distance between the last row and the top of the embankment is just about L_n, as shown in Figure 44.

SUMMARY

This chapter presents design guidelines for LSFs developed using results of the CFD simulations presented in Chapter 4. The goal of these guidelines is to make use of the available right-of-way and prevent snow deposition on the roadway. This approach differs from past design procedures that focus on storing deposited snow for an entire season. These procedures may result in setbacks larger than the available right-of-way. Different guidelines are presented here for sites with flat terrains (slopes less than 15° from horizontal) and those with embankments (slopes up to 34°). On flat terrains, closely spaced rows of vegetation (< 5*H*) produce the same results as a single fence with the same porosity. Multiple rows of vegetation will reduce the porosity compared to a single row of the same species. The recommended configuration for embankments includes an LSF at the base followed by additional rows on the slope. The multiple rows encourage snow deposition along the slope of the embankment, reducing the amount of snow available to deposit on top of the embankment. A spreadsheet is available in Appendix H to assist in designing LSFs on flat terrain and embankments.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions of this research project, followed by recommendations derived from the findings.

CONCLUSIONS

This section summarizes the key findings from the tasks of this research project.

- This project reviewed both the literature and survey responses from practitioners in northern states. Recently, more and more departments of transportation (DOTs) recognize the benefits of snow fences and are enrolling or planning to implement snow fence programs, especially living snow fences. The survey results show that almost all responding agencies have launched snow fence programs in their districts, with various design and siting protocols according to specific conditions. Factors that affect effectiveness and efficiency were investigated to show the design policies for snow fences. Height, porosity, and length of a snow fence are the main design parameters, while the bottom gap and wind direction should also be considered. The siting location is another important consideration to ensure that the snow fence prevents snowdrifts reaching the roadway. The same design and siting principles developed for structural snow fences also apply for LSFs; some modifications, however, are necessary because the height, porosity, and snowdrift length of LSFs change over time as the plants grow. If designed and sited properly, snow fences can improve road safety and provide other benefits. LSFs are preferred by both DOTs and farmers because they are more cost-effective and beneficial to the environment and landowners. However, some challenges exist when installing snow fences on private land in areas with a narrow right-of-way.

- This work reviewed IDOT's data on snow and ice removal costs (district and statewide, especially the 2017–18 and 2018–19 winter seasons) to determine the extent of resource expenditures dedicated to keeping roads open and to dealing with blowing snow in Illinois. Although the winter weather severity is the main influential factor and it varies from year to year, the winter snow and ice removal labor, equipment, and material expenditures have increased in general over the 2015–16 to 2018–19 winter seasons. Among all nine IDOT districts, district 1 has the highest winter operation expenditures ($17,251,00 to $29,805,000), followed by districts 2, 3, 4, 6, 5, 8, 7, and 9 ($6,403,000 to $12,368,000). IDOT has started to collect the blowing snow expenditure data separately since the 2016–17 season. Although not all team sections responded to the survey, the data from those who responded show that districts 2, 3, 4, and 5 have a higher percentage (30–50%) of blowing snow segments than other districts. It matches the total winter snow and ice removal cost data, indicating blowing snow costs account for a large part of the total winter maintenance expenditure. This was confirmed by the blowing snow removal cost data.

- This work conducted field testing of seven selected LSFs in the state of Illinois highway system to provide data for calibrating the numerical model and to evaluate the effectiveness of LSFs. The activities included site selection, site setup, site monitoring, data collection, and analysis. For each site, snow depths were measured to catch the snow deposition pattern and determine the potential of LSF to capture snow. The test sites were monitored over two winter seasons and several snow events were recorded for each winter. Volumes of snow deposited at snow fence sites were calculated to compare them with those from their controls. From the data collected, in general, snow deposition was higher immediately behind the snow fence barrier and decreased gradually with the increase in distance from the snow fence toward the roadway. The tested LSFs in Illinois that are within a ROW were effective in trapping blowing snow despite not having the long setback distance from the roadway, as suggested by past studies. No evidence showed that high-volume snow was deposited on the roadway at those sites. This finding reveals that the proper snow fence setback distance should consider the local prevailing winter weather conditions and snow fences within ROW can still be beneficial to agencies.

- A series of numerical simulations of flow around porous fences were performed using the computational fluid dynamics (CFD) software Flow-3D. The modeling approach was validated using laboratory data collected in a wind tunnel for flow around a fence with nonuniform porosity. Following validation, the numerical approach was used to test a model for fence porosity and investigate the effect of row spacing for fences comprised of two rows of vegetation. The simulations focused on a range of average wind speeds and fence porosity over flat terrain, and the results of these simulations were used to estimate the region of snow deposition using a threshold shear velocity. For sites where the terrain cannot be considered flat, simulations were performed for an embankment with a variety of fence configurations.

- The CFD simulations provide an estimate of the length of the region where snow deposition is expected as a function of fence characteristics. Subsequently, the results of the simulations are employed to develop design guidelines for LSFs. These guidelines are presented for siting LSFs on flat terrain and those with mild slopes (< 15° from horizontal). Guidance is provided for determining fence setback, wind characteristics, fence orientation, as well as fence height and porosity. Fences comprised of multiple rows, such as standing rows of corn, are also addressed. For sites with embankments with steeper slopes, guidelines are provided that include a fence at the base and one or more fence on the embankment.

- The design procedure uses the available ROW at a site to determine the appropriate fence characteristics (e.g., height and porosity) to prevent snow deposition on the road. This approach of using the available length for deposition to determine the fence characteristics differs from prior snow fence design procedures. Past procedures estimate the total snow transport during a season and determine the fence characteristics and setback required to store snow away from the road for an entire season. While those designs have been effective, the resulting setback may be difficult to achieve at sites with limited ROW. The procedure developed in this work (embodied in a design spreadsheet tool) provides an alternative that uses available setback to design the fence. This approach does not consider the snow transport over an entire season and may be less effective in years with several large snowfall events, very large single events, or a sequence of small events with little snowmelt in between. However, this procedure is expected to be effective for the more frequent snowfall events such as those that occurred over the field-monitoring period.

RECOMMENDATIONS

This section presents a list of recommendations to facilitate the implementation of research results by IDOT and translate them into practice. Suitable recommendations will be considered for inclusion in the *Bureau of Design and Environment* manual and the *Operations Maintenance Policy* manual.

Proposed Process Flow for Establishing LSFs for Illinois Highways

This subsection describes the proposed process flow for establishing LSFs for Illinois highways. Figure 46 illustrates the steps, once the drivers or supervisors are trained on how to recognize and report blowing snow issues:

Step 1: Plow drivers or supervisors record blowing snow problem areas by route within a district. The information should include digital photos, date, and location. These assessments should ideally be made during and after two events that created blowing snow problems.

Step 2: Compile all route problem areas per district.

Step 3: Compile all district data into a statewide snowdrift problem area database.

Step 4: Have districts prioritize problem areas per route and district, with 1 as most urgent and 3 as least urgent.

Step 5: Have field personnel visit each highly prioritized area per route and district and conduct a thorough site survey of each blowing snow problem area. Site inventory would include delineation or measuring of area (road shoulder edge to ROW fence and total length of problem area), listing existing woody vegetation (accompanied by site-specific photographs). Note any unusual circumstances on site (water courses, power lines, signage, underground utilities, etc.), adjacent land use and tillage operations, and whether the site is wet or dry. Calculate the fetch, using current aerial photos or other electronic geographic data sources, which may be done in the office. For a known problem area, the value of fetch might be of less importance but still useful to have.

Step 6: Take field notes to the office to compile and create individual surveys of each problem area per route and district. Use local area weather history information sources or what is available, correlate each site with prevailing wind direction, orientation, and any other available information to begin to develop scaled area mapping. Utilize as-built or other GIS information to develop site survey maps. These maps can be used to markup other aspects that may be important on each site.

Step 7: Utilize county soil maps by the Illinois Soil Conservation Service to identify parent soil types for each site.

Step 8: Develop scaled site-development schematics for each site.

Step 9: Utilize the LSF design model, plug in the necessary parameters to select most appropriate LSF plant species, number of rows, spacing, etc.

Step 10: Calculate site-preparation needs. Develop the methods and cost by site, route, and district.

Step 11: Compile the statewide (aggregated) district site-preparation needs.

Step 12: Utilize the list of plant species for Illinois LSF (Appendix E) and select the species that are most appropriate for each site.

Step 13: Compile plant needs list by route and district.

Step 14: Compile statewide plant list needs by district.

Step 15: Create a bid tender for acquisition of plants needed by district and statewide. Bid tender would include plant species, number, size, in what form and where to be delivered, price per plant, and cumulative price delivered. A plant guarantee may or may not be included.

Step 16: Identify all Illinois nurseries who could successfully contract grow and supply the needed plants. Potential Illinois nurseries for LSF plants are listed in Appendix F.

Step 17: Mail bids to vendors and award vendors contract on ability to meet bid requirements.

Step 18: Conduct site preparation work either in the fall or spring or when most convenient. Some of this work might be contracted. Allow time for sites to lie fallow for a period prior to planting. It is assumed that no planting would be done during the summer months (too hot or dry) or when the ground is frozen.

Step 19: Be prepared to accept plant deliveries at district facilities. This must include cool storage, water availability, and perhaps mulch to “heal in” bare root stock. There is a shelf life on these living plants, and planting operations should commence upon delivery and be completed as soon as possible. Have all materials needed for installation available prior to plant arrival and actual field planting. Consider all available sources for assistance in planting operations (community service workers, correctional facilities, service organizations, etc.).

Step 20: Compile a list of potential partners and co-collaborators. These entities could be instrumental in not only funding specific sites but also installation and follow-up care (similar to adopt-a-highway programs). Appendix G presents some considerations for partnerships on implementing LSFs.

Step 21: Plant LSF and conduct follow-up maintenance as needed. This will likely be a three-year process. Maintenance activities may include watering, weeding, herbicide spraying, mowing, cultivation, thinning, and pruning. These post-planting maintenance services might also be contracted or accepted by volunteer organizations.

Step 22: Conduct routine site inspections to determine establishment progress. Note any deficiencies and make plans for corrections.

Step 23: Consider using public media and other means of communication to highlight the rationale and successes of the LSF efforts. These include social media, local radio or TV stations, designated webpage, etc. to enhance positive public relations and build rapport for sound ecological practices and public safety.

Note: Establish a means to determine when a satisfactory level of LSF maturity and efficiency has been achieved. This may be an annual visual analysis or through other quantitative means.

Proposed flow of processes for establishing living snow fence (LSF) for Illinois Highways

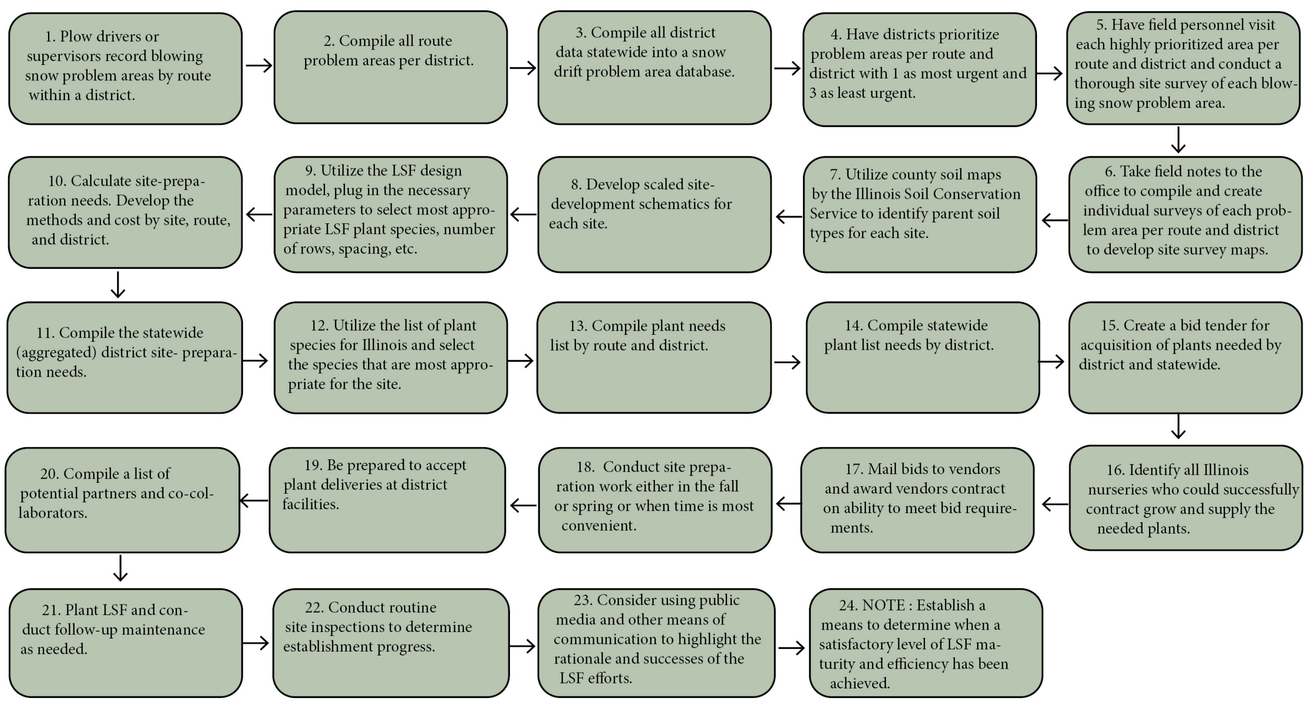


Figure 46. Chart. Proposed process flow for establishing LSFs for Illinois highways.

LSF Siting and Design Guidelines

As embodied in the design spreadsheet tool, different guidelines are presented here for sites with flat terrains (slopes less than 15° from horizontal) and those with embankments (slopes up to 34°). The spreadsheet is available to assist in designing LSFs on flat terrain and embankments. On flat terrain, fences should generally be oriented parallel to the road to minimize the number of plants and the land required. When the angle of attack of the prevailing wind relative to the fence is below 55°, the fence becomes less effective and alternate measures to control blown snow should be considered. For roads that change direction, maintaining continuity of the fence is more important than the angle of attack. Breaks in a fence may result in high wind speeds through the opening that carry large amounts of snow, creating local hazards. For this reason, it is also recommended that spacing between individual plants be selected to maintain continuity of the porous barrier and avoid openings. A list of plants and shrubs is included in this report (Appendix E) to assist in selecting appropriate vegetation. On flat terrain, closely spaced rows of vegetation (< 5*H*) produce the same results as a single fence with the same porosity. Multiple rows of vegetation will reduce the porosity compared to a single row of the same species. The recommended configuration for embankments includes an LSF at the base followed by additional rows on the slope. These multiple rows encourage snow deposition along the slope of the embankment, reducing the amount of snow available to deposit on top of the embankment.

The design procedures presented here use the available right-of-way as the basis of design. The goal of the design process is to determine fence characteristics that result in snow deposition in the right-of-way and not on the road. This approach does not consider snow storage over an entire season but rather focuses on reducing blown snow during events that are more frequent. Design procedures are already available to determine fence characteristics to store snow over an entire season. By combining past procedures with the procedure presented here, a cost-benefit analysis can be performed to determine if the land required for additional snow storage is justified.

Other Implementation Considerations

Once IDOT identifies the areas needing LSFs across the state, an aggregate quantity of acreage needing modification can be created. Then, cost estimates should be prepared as to how much funding will be needed and how much human resources will be required to accomplish the task. By breaking down each individual parcel into smaller units, one can begin to get a handle on expenditures needed for a statewide effort.

Because the ROW widths are often limited, breaking down the areas into 12′ x 100′ (one row, 0.027 acres), or 24′ x 100′ (two rows, 0.055 acres) can make calculating site preparation and materials costs easier. These numbers are then multiplied by each site to an aggregate number. Simple math from field notes determines the area needed for clearing and soil preparation. Once the soil preparation work is complete, a planting design can be developed based on the LSF model and reference materials in the LSF plant species list. Based on plant spacing, the number of plants required per 100 lineal feet can be determined. Additional materials needed can be estimated from plant totals or square footage.

With all site work, appropriate utility clearance would be required. Individual site visits can determine the volume of woody vegetation that will need to be removed prior to conducting soil preparation work. Tree removal or site clearance companies can be chosen to bid on numerous sites within a district. If significant woody vegetation exists on site, the contractor could be advised to save any mulch materials that might result from tree and shrub clearance. IDOT could contact local or regional tree care companies to see if they might provide their tree grindings for future planting use. These mulch piles could be stored at district yards for future LSF planting use or some other location mutually beneficial to both parties. If the site contains only herbaceous plant material, a contact herbicide could be used to kill existing vegetation prior to field tillage operations. Perhaps local area farmers could be hired to conduct these types of soil preparation activities.

Determinations on size of plant or mode of plant delivery (bare root, container, balled, burlapped, etc.) can be made, thereby creating a composite list of plants needed per individual site and then multiple sites. In-state nurseries could be contacted with the idea of contract growing large volumes of specific plants. In some instances, a local farm could grow seedlings or produce rooted cuttings for selected growers to "grow out" in their nurseries for future deliveries. This could enable more species diversity as well as native ecotypes of Illinois.

Once site preparation and plant costs are known, individual sites are now ready to determine planting costs. Actual installation of plants could be accomplished several ways. Plantings could be completed by in-house IDOT personnel or interns. IDOT personnel would provide planting oversight and assistance through all phases of installation. Individual landscape contractors could be solicited to bid for planting and installation care through a given establishment period. This would likely be more costly than in-house planting, but staff would not have to be diverted from normal work. The last and perhaps most intriguing solution for installation would be through an adopt-a-highway kind of program. Such a program within IDOT would oversee the effort to seek out volunteer organizations that are interested in implementing a given area of LSF plantings. IDOT district personnel would provide field support through the planting phases and post care. IDOT district personnel would need to provide appropriate lane shoulder protection and personal protective equipment. The selected volunteer groups would likely be interested in having some input into plant selection.

LSF Research Needs

This subsection describes the research needs identified from this project.

- *Strategies to enable partnerships* with adjacent landowners to expand the size of LSFs.
- *Alternative use of ROW* and the associated cost-benefit analysis. For instance, sections of ROW could be leased for commercial purposes (e.g., production of biomass or another commodity), while implementing LSFs.
- *Better quantification of the costs and benefits* of implementing LSFs at various roadway sites. This would include the quantification of the traffic safety benefits (accident reductions) and positive environmental advantages of LSFs (e.g., air pollution mitigation, wildlife habitat, pollinator habitat enhancement, wind-blown soil mitigation, improved stormwater management strategies, and carbon sequestration). How do various LSFs affect motorist visibility during blowing snow incidents or during other times? Will LSF create conflicts with commercial billboard advertising? Will LSFs create more problems for litter control? If so, how can these be remedied? How much does the implementation of

LSF reduce the quantities of road salt required to provide the same level of service on highways? How does LSF and adjacent natural prairie planting affect the overall cost of winter road maintenance operations? Would the existence of LSF increase the risk of animal-vehicle accidents? Might the incorporation of native LSF and adjoining naturalized prairie plantings minimize the proliferation of invasive species?

- How do the *characteristics of the snow* (e.g., moisture content), different *modes of snow transport* (creep, saltation, and suspension), and *field tillage operations* on lands adjacent to ROW affect the snow deposition and effectiveness of LSFs?

- What are *the most economical means* for implementing various LSFs?

- Upon examining how different plant species react to coppicing, investigate methods and best species for *coppicing procedures* to maximize effectiveness of LSFs.

- *How do environmental factors affect* the performance and longevity of various LSFs? Topics could include wind-blown soil deposition, road salt accumulation in soils, insect and disease pest impacts on growth and mortality, air pollution from vehicles, temperature variations caused by increased paving, soil compaction, and adjacent landowner pesticide use.

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APPENDIX A: COMPLIED WINTER SNOW AND ICE REMOVAL EXPENDITURES

Items	Year	District 1	District 2	District 3	District 4	District 5	District 6	District 7	District 8	District 9	Statewide Total
Labor Expenditure (includes snow & ice activity only) THOUSANDS OF DOLLARS	2015-2016	$6,280,611	$1,953,976	$1,941,025	$1,982,797	$1,142,019	$1,250,844	$1,013,914	$878,545	$893,468	$17,337,199
	2016-2017	$6,075,000	$1,981,000	$1,565,000	$1,699,000	$940,000	$1,025,000	$731,000	$838,000	$385,000	$15,239,000
	2017-2018	$8,892,000	$3,120,000	$3,368,000	$3,063,000	$2,011,000	$2,059,000	$1,334,000	$1,113,000	$973,000	$25,933,000
	2018-2019	$11,781,000	$3,852,000	$3,671,000	$3,422,000	$2,096,000	$2,386,000	$1,571,000	$1,675,000	$1,180,000	$31,634,000
Total Labor Hours (includes snow & ice activity only) THOUSANDS OF HOURS	2016-2017	160400	49700	40900	46700	24700	25600	18800	20400	11000	398200
	2017-2018	233400	76600	83800	77200	47100	45900	31200	24600	24000	643800
	2018-2019	299500	102000	93600	93000	55400	64700	39400	43900	31500	823000
Equipment Expenditure (includes snow & ice activity only)THOUSANDS OF DOLLARS	2015-2016	$4,424,774	$1,509,758	$1,480,783	$1,226,175	$963,653	$1,700,688	$1,047,649	$587,065	$577,607	$13,518,152
	2016-2017	$4,023,000	$2,607,000	$2,015,000	$1,111,000	$775,000	$909,000	$871,000	$569,000	$334,000	$13,214,000
	2017-2018	$6,267,000	$3,129,000	$3,998,000	$2,062,000	$1,808,000	$1,607,000	$980,000	$772,000	$736,000	$21,359,000
	2018-2019	$7,051,000	$2,951,000	$3,958,000	$2,422,000	$1,377,000	$1,301,000	$861,000	$910,000	$909,000	$21,740,000
Material Expenditure (includes snow &ice activity only) THOUSANDS OF DOLLARS	2015-2016	$8,107,340	$2,939,395	$2,554,503	$1,408,611	$866,583	$1,510,404	$821,205	$1,258,279	$1,280,275	$20,746,595
	2016-2017	$7,153,000	$2,941,000	$2,385,000	$1,667,000	$1,163,000	$1,802,000	$798,000	$1,541,000	$439,000	$19,889,000
	2017-2018	$9,593,000	$4,131,000	$3,662,000	$2,281,000	$1,574,000	$2,634,000	$1,324,000	$1,459,000	$1,251,000	$27,909,000
	2018-2019	$10,973,000	$4,631,000	$4,739,000	$3,283,000	$1,674,000	$3,159,000	$1,609,000	$3,002,000	$1,879,000	$34,949,000
Total Expenditure (includes snow and ice activity only) THOUSANDS OF DOLLARS	2015-2016	$18,812,725	$6,403,129	$5,976,311	$4,617,583	$2,972,255	$4,461,936	$2,882,768	$2,723,889	$2,751,350	$51,601,946
	2016-2017	$17,251,000	$7,529,000	$5,965,000	$4,477,000	$2,878,000	$3,736,000	$2,400,000	$2,948,000	$1,158,000	$48,342,000
	2017-2018	$24,751,000	$10,380,000	$11,028,000	$7,407,000	$5,393,000	$6,300,000	$3,638,000	$3,344,000	$2,960,000	$75,201,000
	2018-2019	$29,805,000	$11,434,000	$12,368,000	$9,127,000	$5,147,000	$6,846,000	$4,041,000	$5,587,000	$3,968,000	$88,323,000
Salt Usage (Thousands of Tons)	FY 14	323.6	85.2	82	54.3	34.7	63.3	43.7	72	40	798.8
	FY 15	178.1	54.9	51.3	28.3	20.4	42.2	21.2	37	28	461.5
	FY 16	129.5	41.8	38.6	21.5	12.4	23	11.3	19.6	18	315.8
	FY 17	113.9	41.8	36.6	25.9	17	27.6	11.1	24.1	6.4	304.1
	FY 18	206.3	77.2	72.1	44.9	27.9	48	22.5	29.5	21.5	549.9
	FY 19	214	81.2	71.8	51.2	26.1	49.5	22	49.7	30.1	595.6
Salt On Hand as % of Capacity by District	2016-2017	104	78	88	79	90	80	114	86	89	91
	2017-2018	71	44	53	57	64	38	88	78	65	62
	2018-2019	69	52	35	61	76	40	75	58	65	58
Total Trucks	2015-2016	419	161	184	154	154	189	154	197	135	1747
Required Trucks - Single Axle Dump	2015-2016	128	106	116	93	105	131	127	150	86	1041
Required Trucks - Tandems	2015-2016	279	46	59	52	48	56	27	47	49	664
Required Trucks - 4x4's	2015-2016	7	6	9	9	1	2	0	0	0	34
Required Trucks - Rotary	2015-2016	5	3	0	0	0	0	0	0	0	8
Lane Miles Plowed	2015-2016	8688	3870	4209	4237	3569	5585	4150	5123	3755	43186
	2018-2019	10,191	4,064	4,170	4,230	3,348	5,475	4,141	5,102	3,624	44,347
Counties Served	2015-2016	6	10	9	12	7	15	16	11	16	102
Permanent Employees	2015-2016	380	161	142	141	128	151	156	229	126	1614
Temporary Employees	2015-2016	580	217	260	190	245	163	216	195	171	2237
Number of Truck Routes	2015-2016	574	127	108	87	86	154	93	123	83	1235

Figure 47. Chart. Compiled winter snow and ice removal expenditures (I).

Items	Year	Statewide Total	Items	Year	Statewide Total	Items	Year	Statewide Total
Total Maintenance Cost (**Labor**) Millions of Dollars	FY 14	$158.4 M	Total Maintenance Cost (**Equipment**) Millions of Dollars	FY 14	$74.1M	Total Maintenance Cost (**Material**) Millions of Dollars	FY 14	$53.2M
	FY 15	$154.20		FY 15	$65.10		FY 15	$34.90
	FY 16	$147.60		FY 16	$24.70		FY 16	$29.30
	FY 17	$143.30		FY 17	$10.30		FY 17	$29.30
	FY 18	$152.50		FY 18	$66.60		FY 18	$37.80
	FY 19	$145.20		FY 19	$54.90		FY 19	$39.80
Overtime Cost (includes all work activities) Millions of Dollars	FY 14	$34.10	**Extra Help Cost (includes all work activities) Millions of Dollars**	FY 14	$28.50	**Fuel Consumption on-road equipment** (includes all work activities) (millions of gallons)	FY 14	4.8
	FY 15	$19.40		FY 15	$21.20		FY 15	3.8
	FY 16	$13.60		FY 16	$19.90		FY 16	3.3
	FY 17	$13.20		FY 17	$19.70		FY 17	3.1
	FY 18	$22.20		FY 18	$23.20		FY 18	3.8
	FY 19	$23.80		FY 19	$16.50		FY 19	3.81
Fuel Cost on-road equipment (includes all work activities) (millions of	FY 14	$17.50	**Fuel Consumption total** (includes all work activities) (millions of	FY 14	5.4	**Fuel costs total** (includes all work activities) (millions of dollars)	FY 14	$19.60
	FY 15	$10.80		FY 15	4.3		FY 15	$12.50
	FY 16	$6.90		FY 16	3.9		FY 16	$8.30
	FY 17	$6.50		FY 17	3.6		FY 17	$7.50
	FY 18	$9.20		FY 18	4.2		FY 18	$10.20
	FY 19	$10.37		FY 19	4.26		FY 19	$11.64

Figure 48. Chart. Compiled winter snow and ice removal expenditures (II).

APPENDIX B: QUESTIONNAIRE AND RESULTS FOR IDOT OPERATION SUPERVISORS AND FIELD ENGINEERS

1. Do you have Team Sections with typical blowing snow problems in which you have to keep HM's after a snow event just to deal with blowing and cleanup of roads due to blowing snow?

   YES / NO

2. List the Teams Sections that have:
   1. Interstate Blowing problems TS_____;TS_____;TS_____;TS_____;TS_____
   2. Rural route blowing problems TS_____;TS_____;TS_____;TS_____;TS_____

   (Many Team Sections will have both)

3. List the Snow routes in each team section that have blowing problems at times during the winter. You know all your typical blowing problem areas. Review each snow route and roughly identify how many lane miles have blowing problems. Take each routes blowing segments and add them together to get a rough total miles involved. For example an interstate snow route has 5 separate blowing segments. Each segment is 1/4 mile long and involves all four lanes. Total lane miles would equal ¼ X 4 = 1 lane mile X 5 segments totaling 5 lane miles long.

   a. Team Section____________ Snow Route _______________
      i. Total Interstate lane miles of route ______
      ii. Total Rural/Primary lane miles of route________
      iii. Typical blowing segment lane miles of route______

   b. Team Section____________ Snow Route _______________
      i. Total Interstate lane miles of route ______
      ii. Total Rural/Primary lane miles of route________
      iii. Typical blowing segment lane miles of route______

   c. Team Section____________ Snow Route _______________
      i. Total Interstate lane miles of route ______
      ii. Total Rural/Primary lane miles of route________
      iii. Typical blowing segment lane miles of route______

d. Team Section_____________ Snow Route ________________
   i. Total Interstate lane miles of route _______
   ii. Total Rural/Primary lane miles of route_________
   iii. Typical blowing segment lane miles of route_______
e. Team Section_____________ Snow Route ________________
   i. Total Interstate lane miles of route _______
   ii. Total Rural/Primary lane miles of route_________
   iii. Typical blowing segment lane miles of route_______
f. Team Section_____________ Snow Route ________________
   i. Total Interstate lane miles of route _______
   ii. Total Rural/Primary lane miles of route_________
   iii. Typical blowing segment lane miles of route_______
g. Team Section_____________ Snow Route ________________
   i. Total Interstate lane miles of route _______
   ii. Total Rural/Primary lane miles of route_________
   iii. Typical blowing segment lane miles of route_______
h. Team Section_____________ Snow Route ________________
   i. Total Interstate lane miles of route _______
   ii. Total Rural/Primary lane miles of route_________
   iii. Typical blowing segment lane miles of route_______
i. Team Section_____________ Snow Route ________________
   i. Total Interstate lane miles of route _______
   ii. Total Rural/Primary lane miles of route_________
   iii. Typical blowing segment lane miles of route_______
j. Team Section_____________ Snow Route ________________
   i. Total Interstate lane miles of route _______
   ii. Total Rural/Primary lane miles of route_________
   iii. Typical blowing segment lane miles of route_______
k. Team Section_____________ Snow Route ________________
   i. Total Interstate lane miles of route _______
   ii. Total Rural/Primary lane miles of route_________
   iii. Typical blowing segment lane miles of route_______
l. Team Section_____________ Snow Route ________________
   i. Total Interstate lane miles of route _______
   ii. Total Rural/Primary lane miles of route_________
   iii. Typical blowing segment lane miles of route_______
m. Team Section_____________ Snow Route ________________
   i. Total Interstate lane miles of route _______
   ii. Total Rural/Primary lane miles of route_________
   iii. Typical blowing segment lane miles of route_______

Table 7. District 1 Blowing Snow Segments

Team Section	Snow Route	Total Lane Miles of Route	Interstate Miles	Non-Interstate Miles	Interstate Blowing Snow Miles	Non-Interstate Blowing Snow Miles	% of Route with Blowing Snow
021	Touhy: Algonquin to Wolf Rd.	27.5	0	27.5	0	0.375	1.4%
021	Mannheim from I-190 to IL-19	30.3	0	30.3	0	0.5	1.7%
021	IL-19 (Irving Park) Cumberland Ave to IL-83	30.4	0	30.4	0	2	6.6%
021	IL-171: Higgins to Belmont Ave and Harlem	32.1	0	32.1	0	1.5	4.7%
021	River Road: Grand Ave. to Wolf Rd.	33.7	0	33.7	0	1.5	4.5%
021	Mannheim: Wolf Rd. to Green St.	25.3	0	25.3	0	0.25	1.0%
021	IL-64: Thatcher Ave. to Nichols Rd.	23.7	0	23.7	0	1.5	6.3%
022	19	17.6	0	17.6	0	2.5	14.2%
022	20	32.6	0	32.6	0	0.75	2.3%
022	Harlem Ave/ IL-43 S/B S. of 65th St.	21.2	0	21.2	0	0.25	1.2%
022	Wolf Rd. Harrison to Cermak	22.4	0	22.4	0	0.75	3.3%
031	14/13	22.3	0	22.3	0	2	9.0%
031	3	23.9	0	23.9	0	6	25.1%
031	5	29.3	0	29.3	0	2	6.8%
031	6	43.4	0	43.4	0	5	11.5%
031	8	22	0	22	0	18	81.8%
031	15	25.6	0	25.6	0	13	50.8%
031	17	25.6	0	25.6	0	15	58.6%
031	18	27.7	0	27.7	0	5	18.1%
127	15	27.4	0	27.4	0	1.5	5.5%
127	12	31	0	31	0	1.5	4.8%

127	17	26.1	0	26.1	0	3	11.5%
128	IL-53 from IL-38 to Lake St.	27.2	0	27.2	0	0.75	2.8%
128	IL-19 from IL-83 to IL-53	17.9	0	17.9	0	0.5	2.8%
128	IL-56 from 22nd to Cadwell St.	12.3	0	12.3	0	0.5	4.1%
128	Ramps York Rd. EB to IL-38 and SB York Exit	10.1	0	10.1	0	0.1	1.0%
E-26	M-1	32.5	0	32.5	0	12	36.9%
E-26	R-1	4.5	0	4.5	0	2	44.4%
District Totals		705.6	0	705.6	0	99.7	14.1%

Table 8. District 2 Blowing Snow Segments

Team Section	Snow Route	Total Lane Miles of Route	Interstate Miles	Non-Interstate Miles	Interstate Blowing Snow Miles	Non-Interstate Blowing Snow Miles	% of Route with Blowing Snow
221	S-1a	16.5	0	16.5	0	10	60.6%
221	S-2	33.8	0	33.8	0	2	5.9%
221	S-3	34	0	34	0	30	88.2%
221	S-4	27.6	0	27.6	0	10	36.2%
221	S-5	36.6	0	36.6	0	15	41.0%
221	S-6	39.3	0	39.3	0	15	38.2%
221	S-7	35.9	0	35.9	0	10	27.9%
221	S-8	39.1	0	39.1	0	30	76.7%
221	S-9	39.2	0	39.2	0	30	76.5%
District Totals		302	0	302	0	152.0	50.3%

Table 9. District 3 Blowing Snow Segments

Team Section	Snow Route	Total Lane Miles of Route	Interstate Miles	Non-Interstate Miles	Interstate Blowing Snow Miles	Non-Interstate Blowing Snow Miles	% of Route with Blowing Snow
321	I-57 (NB)	50.1	50.1	0	24	0	47.9%
321	I-57 (SB)	51.8	51.8	0	24	0	46.3%
321	IL 50	60.5	0	60.5	0	14	23.1%
321	45 N	16.8	0	16.8	0	8	47.6%
321	45 S	39.4	0	39.4	0	8	20.3%
321	1/114	43.6	0	43.6	0	20	45.9%
321	1/17.	37	0	37	0	32	86.5%
321	17 E	24.4	0	24.4	0	18	73.8%
321	17 W	38.8	0	38.8	0	32	82.5%
321	102/113	35	0	35	0	12	34.3%
322	1	34	0	34	0	14	41.2%
322	2	30	0	30	0	8	26.7%
322	3	23	0	23	0	12	52.2%
322	4	26	0	26	0	9	34.6%
322	5	22	0	22	0	10	45.5%
322	6	20	0	20	9	8	85.0%
322	7	43	0	34	0	22	51.2%
322	8	23	0	23	0	8	34.8%
322	9	28	0	28	0	14	50.0%
322	WA-1	18	0	18	0	14	77.8%
322	WA-2	14	0	14	0	3	21.4%
322	WA-3	12	0	12	0	8	66.7%
322	WA-4	14	0	14	0	5	35.7%
322	WA-5	11	0	11	0	4	36.4%
322	WA-6	11	0	11	0	4	36.4%
322	WA-7	16	0	16	0	7	43.8%
322	WA-8	12	0	12	0	6	50.0%
322	WA-9	14	0	14	0	6	42.9%
323	A1 I-57	49.85	49.85	0	0.5	0	1.0%
323	A2 I-57	53.59	53.59	0	1	0	1.9%
323	A3 I-57	53.13	53.13	0	1	0	1.9%
323	A4 I-57	39.53	39.53	0	1.5	0	3.8%
323	A5 US 45/52	25.3	0	25.3	0	1	4.0%
323	A6 IL 116	35.14	0	35.14	0	1	2.8%
323	A9	37.96	0	37.96	0	1	2.6%
334	I-55 S	77.2	77.2	0	0	30	38.9%
334	I-55 N	52.7	52.7	0	0	35	66.4%
334	OLD 66 S	47.8	0	47.8	0	15	31.4%
334	OLD 66 N	40	0	40	0	16	40.0%
334	IL 116 W	32.6	0	32.6	0	16	49.1%

Team Section	Snow Route	Total Lane Miles of Route	Interstate Miles	Non-Interstate Miles	Interstate Blowing Snow Miles	Non-Interstate Blowing Snow Miles	% of Route with Blowing Snow
334	IL 23 N	35.4	0	35.4	0	16	45.2%
334	IL 17 W	41	0	41	0	30	73.2%
334	IL 17/ IL 170	30.8	0	30.8	0	16	51.9%
334	IL 17 E	33.2	0	33.2	0	14	42.2%
334	IL 47 N	30.6	0	30.6	0	10	32.7%
334	IL 116 E	41.4	0	41.4	0	24	58.0%
334	IL 47/US 24 E	38.2	0	38.2	0	12	31.4%
334	IL 47/US 24 W	37.2	0	37.2	0	12	32.3%
334	IL 23 S	32.5	0	32.5	0	14	43.1%
336	1	30	0	30	0	22	73.3%
336	2	24	0	24	0	14	58.3%
336	3	26	0	26	0	12	46.2%
336	4	34	0	34	0	16	47.1%
336	5	42	0	42	0	30	71.4%
336	6	32	0	32	0	20	62.5%
336	7	28	0	28	0	16	57.1%
336	8	18	0	18	0	14	77.8%
343	1	55.4	48	7.4	20	2.5	40.6%
343	2	50.5	0	50.5	0	4	7.9%
343	3	61.3	0	61.3	0	32	52.2%
343	4	46.6	0	46.6	0	20	42.9%
343	5	33.8	0	33.8	0	12	35.5%
343	6	31.8	0	31.8	0	23	72.3%
343	7	43	0	43	0	30	69.8%
343	8	36	0	36	0	25	69.4%
343	9	36.2	0	36.2	0	10	27.6%
344	1	54.6	0	54.6	8	0	14.7%
344	2	35.6	0	35.6	0	33	92.7%
344	3A	29.8	0	29.8	0	12	40.3%
344	3B	38.8	0	38.8	0	8	20.6%
344	4	34.2	0	34.2	0	10	29.2%
344	5	57.8	0	57.8	0	52	90.0%
344	6	49.6	49.6	0	40	0	80.6%
344	7	72.7	72.7	0	52	0	71.5%
344	8	42	42	0	42	0.0	100.0%
345	1	38.4	0	38.4	0	32	83.3%
345	2	36.8	0	36.8	0	36.8	100.0%
345	3	37.6	0	37.6	0	37.6	100.0%
345	4	36.6	0	36.6	0	26	71.0%
345	5	41.4	0	41.4	0	41.4	100.0%
345	6	40	0	40	0	32	80.0%

Team Section	Snow Route	Total Lane Miles of Route	Interstate Miles	Non-Interstate Miles	Interstate Blowing Snow Miles	Non-Interstate Blowing Snow Miles	% of Route with Blowing Snow
345	7	28.6	0	28.6	0	20	69.9%
345	8	52	52	0	28	0	53.8%
345	9	53	49	0	20	0	37.7%
346	1	23	0	23	0	15	65.2%
346	2	20	0	20	0	18	90.0%
346	3	14	0	14	0	7	50.0%
346	4	16	0	16	0	10	62.5%
346	5	23	0	23	0	19	82.6%
346	6	20	0	20	0	15	75.0%
347	1	57.6	57.6	0	25	0	43.4%
347	3	30.5	0	30.5	0	30.5	100.0%
347	4	42.5	0	42.5	0	10	23.5%
347	5	85	85	0	6	0	7.1%
351	I-80	137	137	0	33		24.1%
351	US 6	58.6	0	58.6	0	11	18.8%
351	IL 47	68	0	68	0	19	27.9%
351	IL 113	21.3	0	21.3	0	7.25	34.0%
351	I-55	76	76	0	13	0	17.1%
352	US 52	38	0	38	0	25	65.8%
352	US34, IL25,IL31	42	0	42	0	13.5	32.1%
352	Rt 47	42	0	42	0	20	47.6%
352	34/IL 47 N	41	0	41	0	11	26.8%
352	IL 126	23	0	23	0	18	78.3%
352	IL 72	47	0	47	0	25	53.2%
District Totals		3967.1	1096.8	2857.3	348	1486.6	46.2%

Table 10. District 4 Blowing Snow Segments

Team Section	Snow Route	Total Lane Miles of Route	Interstate Miles	Non-Interstate Miles	Interstate Blowing Snow Miles	Non-Interstate Blowing Snow Miles	% of Route with Blowing Snow
411A	1	42	0	42	0	14.5	34.5%
411A	2	42	0	42	0	23	54.8%
411A	3	46	0	46	0	4	8.7%
411A	4	40	0	40	0	11	27.5%
411	5	42	0	42	0	5.5	13.1%
411	6	41	0	41	0	6.5	15.9%
411	7	38	0	38	0	2	5.3%
411	8	30	0	30	0	9.5	31.7%
411	9 and 9A	89	0	89	0	28	31.5%
411	10 and 10A	71	0	71	0	5	7.0%

Team Section	Snow Route	Total Lane Miles of Route	Interstate Miles	Non-Interstate Miles	Interstate Blowing Snow Miles	Non-Interstate Blowing Snow Miles	% of Route with Blowing Snow
411B	11	42	0	42	0	8	19.0%
411B	12	42	0	42	0	8	19.0%
411B	13	40	0	40	0	17	42.5%
411B	14	40	0	40	0	24	60.0%
411B	15	43	0	43	0	4	9.3%
411B	16	38	0	38	0	1.5	3.9%
412	1	42	0	42	0	30	71.4%
412	2	38	0	38	0	12	31.6%
412	3	40	0	40	0	26	65.0%
412	4	45.2	0	45.2	0	2	4.4%
412	5	32	0	32	0	12	37.5%
412	6	37	0	37	0	0	0.0%
412	7	32	0	32	0	6	18.8%
412	6A	35	0	35	0	0	0.0%
421	1	32.8	0	32.8	0	12.6	38.4%
421	2	33.9	0	33.9	0	24.4	72.0%
421	3	35.7	0	35.7	0	23.2	65.0%
421	4	42.3	0	42.3	0	24.1	57.0%
421	5	41	0	41	0	17.9	43.7%
421	6	44.7	0	44.7	0	18	40.3%
421	7	43	0	43	0	8.7	20.2%
421	8	42	0	42	0	16.4	39.0%
421	9	55.9	55.9	0	34.4	0	61.5%
421	10	59.1	59.1	0	22.4	0	37.9%
421	11	50.1	50.1	0	26	0	51.9%
422	1	51	0	51	0	5.2	10.2%
422	2	35	0	35	0	3	8.6%
422	3	41	0	41	0	13.2	32.2%
422	4	44	0	44	0	2.4	5.5%
422	5	52	0	52	0	0	0.0%
422	6	42	0	42	0	1.8	4.3%
422	7	48	0	48	0	0	0.0%
422	8	46	0	46	0	1.4	3.0%
422	9	42	0	42	0	0	0.0%
431	1	48	0	48	0	16.3	34.0%
431	2	46	0	46	0	30	65.2%
431	3	46.4	0	46.4	0	34.5	74.4%
431	4	44.6	0	44.6	0	35.6	79.8%
431	5	39.9	0	39.9	0	30.5	76.4%
431	6	33	0	33	0	5.7	17.3%
431	7	32.8	0	32.8	0	0	0.0%
District Totals		2199.4	165.1	2034.3	82.8	584.4	30.3%

Table 11. District 5 Blowing Snow Segments

Team Section	Snow Route	Total Lane Miles of Route	Interstate Miles	Non-Interstate Miles	Interstate Blowing Snow Miles	Non-Interstate Blowing Snow Miles	% of Route with Blowing Snow
513	1	50.96	34.76	16.2	33	15	94.2%
513	2	44.24	44.24	0	34	0	76.9%
513	3	21.72	0	21.72	0	18	82.9%
513	4	32.9	32.9	0	14	0	42.6%
513	5	31.32	0	31.32	0	28	89.4%
513	6	40.44	0	40.44	0	26.2	64.8%
513	7	30.3	0	30.3	0	27	89.1%
514	1	39	0	39	0	29	74.4%
514	2	43	0	43	0	22	51.2%
514	3	42	0	42	0	18	42.9%
514	4	41.5	0	41.5	0	17.6	42.4%
514	5	39.14	0	39.14	0	28.8	73.6%
514	6	52.1	20.8	31.3	18.6	12.5	59.7%
516	1	60.9	60.9	0	0	0	0.0%
516	2	37.8	0	37.8	0	4.5	11.9%
516	3	59.5	59.5	0	2	0	3.4%
516	4	52	0	52	0	7.5	14.4%
516	5	33.5	0	33.5	0	0.5	1.5%
516	7	61.4	61.4	0	7	0	11.4%
516	8	42.4	0	42.4	0	15	35.4%
516	9	42.8	0	42.8	0	13	30.4%
516	10	27.6	0	27.6	0	1	3.6%
517	1	44.62	44.62	0	10	0	22.4%
517	2	28.57	18	10	1	4	17.5%
517	3	49.74	49.74	0	8	0	16.1%
517	4	60.13	60.13	0	28	0	46.6%
517	5	53.23	53.23	0	14	0	26.3%
517	6	43.68	0	43.68	0	38	87.0%
517	7	42.04	0	42.04	0	3	7.1%
517	8	32.66	0	32.66	0	32.66	100.0%
517	9	38.54	0	38.54	0	36	93.4%
517	10	35.62	0	35.62	0	35	98.3%
517	11	31.72	0	31.72	0	18	56.7%
517	12	31.5	0	31.5	0	27	85.7%
517	13	47.58	0	47.58	0	32	67.3%
522	7	13.9	0	13.9	0	0.5	3.6%

Team Section	Snow Route	Total Lane Miles of Route	Interstate Miles	Non-Interstate Miles	Interstate Blowing Snow Miles	Non-Interstate Blowing Snow Miles	% of Route with Blowing Snow
522	5	17.8	0	17.8	0	2	11.2%
522	4	21.7	0	21.7	0	5	23.0%
522	2	16.6	0	16.6	0	13	78.3%
522	1	16	0	16	0	3	18.8%
522	3	17.7	0	17.7	0	5	28.2%
524	1	16	0	16	0	3.5	21.9%
524	3	19	0	19	0	10	52.6%
524	4	16	0	16	0	1	6.3%
524	5	18	0	18	0	9	50.0%
524	6c	21	21	0	4	0	19.0%
District Totals		1659.85	561.22	1098.06	173.6	561.3	44.3%

Table 12. District 7 Blowing Snow Segments

Team Section	Snow Route	Total Lane Miles of Route	Interstate Miles	Non-Interstate Miles	Interstate Blowing Snow Miles	Non-Interstate Blowing Snow Miles	% of Route with Blowing Snow
710	1	38	0	38	0	28	73.7%
710	2	42	0	42	0	20	47.6%
710	3	35	0	35	0	22	62.9%
710	4	40	0	40	0	14	35.0%
710	5	40.6	0	40.6	0	15	36.9%
711	IL 121 NW	38.75	0	38.75	0	8.25	21.3%
711	IL 121 SE	46.27	0	46.27	0	12.41	26.8%
711	US 51 N	53.48	0	53.48	0	8.65	16.2%
711	US 51 S	53.08	0	53.08	0	7.41	14.0%
711	48 N to I-72	40.12	0	40.12	0	3.9	9.7%
711	48 S	36.81	0	36.81	0	1.06	2.9%
711	105 E	39.8	0	39.8	0	10.87	27.3%
711	Old 36 W	44.27	0	44.27	0	6	13.6%
712	5	45	0	45	0	20	44.4%
712	6	57	0	57	0	10	17.5%
713	1	70	70	0	20	0	28.6%
713	2	79	79	0	30	0	38.0%
713	3	111	111	0	53	0	47.7%
713	4	53	0	53	0	15.0	28.3%
713	5	48	0	48	0	15	31.3%
713	6	43	0	43	0	10	23.3%
713	7	49	0	49	0	12	24.5%
713	8	36	0	36	0	20	55.6%

Team Section	Snow Route	Total Lane Miles of Route	Interstate Miles	Non-Interstate Miles	Interstate Blowing Snow Miles	Non-Interstate Blowing Snow Miles	% of Route with Blowing Snow
713	9	67	0	67	0	7	10.4%
713	10	63	63	0	0	10	15.9%
715	4	30	0	30	0	20	66.7%
715	5	37	0	37	0	37	100.0%
715	6	28	0	28	0	20	71.4%
721	1	34.8	0	34.8	0	2	5.7%
721	2A	31.7	0	31.7	24	0	75.7%
721	2B	25.7	0	25.7	10	0	38.9%
721	3	30.4	0	30.4	0	12	39.5%
721	4	35.6	0	35.6	0	18	50.6%
721	5	35.2	0	35.2	4	0	11.4%
721	6	34.1	0	34.1	0	18	52.8%
721	7	33.8	0	33.8	0	18	53.3%
721	8	37.6	0	37.6	0	8	21.3%
721	9	37.3	0	37.3	0	28	75.1%
721	10	28.1	0	28.1	0	8	28.5%
721	11	27.8	0	27.8	0	6	21.6%
721	12	28	0	28	0	6	21.4%
722	1	39.3	24	15.3	0.5	1.5	5.1%
722	2	38.3	0	38.3	0	6	15.7%
722	3	35.6	0	35.6	0	19	53.4%
722	4	35.4	0	35.4	0	6	16.9%
722	5	35.8	0	35.8	0	9.4	26.3%
722	6	38.3	0	38.3	0	7.2	18.8%
722	7	38.6	0	38.6	0	2.5	6.5%
722	8	36.8	0	36.8	0	4.30	11.7%
722	9	38.6	0	38.6	0	12.2	31.6%
722	10	40.8	0	40.8	0	3.2	7.8%
722	11	41.3	0	41.3	0	6	14.5%
722	12	41.8	0	41.8	0	11.2	26.8%
723	1 Clay	42.68	0	42.68	0	16	37.5%
723	2 Clay	36.76	0	36.76	0	14	38.1%
723	3 Clay	45.36	0	45.36	0	18	39.7%
723	4 Clay	40.68	0	40.68	0	8	19.7%
723	5 Richland	31.86	0	31.86	0	10	31.4%
723	6 Richland	38.77	0	38.77	0	4	10.3%
723	7 Richland	43.22	0	43.22	0	6	13.9%
724	1A	26.48	26.48	0	6	0	22.7%
724	1B	24.05	24.05	0	6	0	24.9%
724	2C	27.79	27.79	0	4	0	14.4%
724	3	41.83	0	41.83	0	15.5	37.1%
724	4	31.96	0	31.96	0	12	37.5%

Team Section	Snow Route	Total Lane Miles of Route	Interstate Miles	Non-Interstate Miles	Interstate Blowing Snow Miles	Non-Interstate Blowing Snow Miles	% of Route with Blowing Snow
724	5	41.51	0	41.51	0	6.4	15.4%
724	6	40.04	0	40.04	0	4.5	11.2%
725	1	35	0	35	0	12	34.3%
725	2C	31.5	31.5	0	12	0	38.1%
725	3	36	0	36	0	8	22.2%
725	4B	14.4	14.4	0	4	0	27.8%
725	5	39	0	39	0	20	51.3%
725	6	41	0	41	0	10	24.4%
741	1 Wayne	47.14	0	47.14	0	10	21.2%
741	2 Wayne	42.49	0	42.49	0	6	14.1%
741	3 Wayne	54.34	0	54.34	0	16	29.4%
741	4 Ed/Wabash	44.12	0	44.12	0	4	9.1%
741	5 Ed/Wabash	41.42	0	41.42	0	8	19.3%
741	6 Ed/Wabash	47.53	0	47.53	0	4	8.4%
741	7 Ed/Wabash	42.94	0	42.94	0	6	14.0%
741	8 Wayne	50.11	50.11	0	1.5	0	3.0%
741	9 Wayne	54.26	54.26	0	4	0	7.4%
District Totals		3379.12	575.59	2803.53	179	784.5	28.5%

Table 13. District 9 Blowing Snow Segments

Team Section	Snow Route	Total Lane Miles of Route	Interstate Miles	Non-Interstate Miles	Interstate Blowing Snow Miles	Non-Interstate Blowing Snow Miles	% of Route with Blowing Snow
912	1	21.3	0	21.3	0	1	4.7%
912	3	20.9	0	20.9	0	20.9	100.0%
912	4	19.2	0	19.2	0	0.25	1.3%
912	5	21.9	0	21.9	0	8	36.5%
913	1	15.2	0	15.2	0	3.5	23.0%
913	3	20.2	0	20.2	0	2	9.9%
913	4	17	0	17	0	3	17.6%
913	5	15.7	0	15.7	0	2	12.7%
914	1	31	0	31	0	8	25.8%
914	4	34	0	34	0	6	17.6%
914	5	37	0	37	0	6	16.2%
914	6	38	0	38	0	10	26.3%
921	3	42	0	42	0	1	2.4%
921	6	38	0	38	0	1	2.6%
921	7	79	0	79	0	1.5	1.9%

Team Section	Snow Route	Total Lane Miles of Route	Interstate Miles	Non-Interstate Miles	Interstate Blowing Snow Miles	Non-Interstate Blowing Snow Miles	% of Route with Blowing Snow
922	1	17.3	0	17.3	0	0.5	2.9%
922	2	37.4	0	37.4	0	4	10.7%
922	3	21.9	0	21.9	0	0.2	0.9%
922	4	28.3	0	28.3	0	3	10.6%
922	5	18.5	0	18.5	0	2	10.8%
922	6	19.7	0	19.7	0	2	10.2%
922	7	18.4	0	18.4	0	5	27.2%
922	8	21.8	0	21.8	0	8	36.7%
922	9	22.9	0	22.9	0	5	21.8%
922	10	20.9	0	20.9	0	8	38.3%
923	2	36	0	36	0	1	2.8%
923	3	40	0	40	0	0.5	1.3%
923	7	43	0	43	0	18	41.9%
923	10	36	0	36	0	1	2.8%
923	12	40	0	40	2	0	5.0%
931	3	13.3	0	13.3	0	0.5	3.8%
931	5	20	0	20	0	1	5.0%
931c	8	12	0	12	0	0.5	4.2%
931c	9	25	0	25	0	1	4.0%
932	3	40	0	40	4	0	10.0%
932	5	28	0	28	0	6	21.4%
932	8	30	0	30	0	6	20.0%
932	9	32	0	32	0	8	25.0%
932	10	30	0	30	0	4	13.3%
942	1	23.9	0	23.9	0	14	58.6%
942	2	23	0	23	0	4	17.4%
942	3	19.5	0	19.5	0	4	20.5%
942	4	22.1	0	22.1	0	10	45.2%
942	5	22.1	0	22.1	0	0.04	0.2%
942	6	18.4	0	18.4	0	8	43.5%
942	7	20.8	0	20.8	0	4	19.2%
District Totals		1252.6	0	1252.6	6	203.4	16.7%

APPENDIX C: SITE FIELD MEASUREMENTS OF SELECTED IDOT LIVING SNOW FENCES

Living Snow Fence Field Measurement Spreadsheet

Date: 01/05/2018
Location Site Number: 3
Location description: I-39 Minonk MM 24

Indigo Bush with/without slated snow fence

Time start:
Time finish:
Observer: PAH,DD
Series of photos taken? Y / N n
Air temp:
Pavement temp:
Wind speed windward:
Wind speed Leeward:
Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	52	43	42		33	24		15		6	5	
Insert numbers for stake here												Slatted fence
	51	44	41	34	32	25	23	16	14	7	4	ROW Fence
Insert numbers for stake here	20"	26"	28"	31"	31"	27"	30"	24"	20"	24"	30"	
	50	45	40	35	31	26	22	17	13	8	3	
Insert numbers for stake here	11"	15"	16"	11"	18"	20"	21"	17"	19"	17"	14"	
	49	46	39	36	30	27	21	18	12	9	2	
Insert numbers for stake here	11"	10"	10"	11"	11"	12"	10"	10"	9"	8"	11"	
	48	47	38	37	29	28	20	19	11	10	1	
Insert numbers for stake here	17"	11"	12"	12"	13"	12"	12"	14"	12"	10"	11"	

Edge of roadway SB I-39

Other notes of importance: no entry = no stake
Note: Actual local area weather information should be included with each report.

Figure 49. Table. I-39 MM 24 site field measurements on January 5, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/11/2018
Location Site Number: 3
Location description: I-39 Minonk MM 24

Indigo bush with/without slated snow fence

Time start: Base Line
Time finish:
Observer: Darrell Tiesman
Series of photos taken? No
Air temp:
Pavement temp:
Wind speed windward:
Wind speed Leeward:
Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	52	43	42		33	24		15		6	5	
Insert numbers for stake here	*	*	*		*	*		*		*	*	Slatted fence
	51	44	41	34	32	25	23	16	14	7	4	ROW Fence
Insert numbers for stake here	0"	12"	13"	10"	12"	12"	2"	0"	0"	0"	1"	
	50	45	40	35	31	26	22	17	13	8	3	
Insert numbers for stake here	0"	0"	0"	0"	0"	5"	1"	0"	0"	0"	0"	
	49	46	39	36	30	27	21	18	12	9	2	
Insert numbers for stake here	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	
	48	47	38	37	29	28	20	19	11	10	1	
Insert numbers for stake here	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	

Edge of roadway SB I-39

Other notes of importance: * = Missing stake.
Note: Actual local area weather information should be included with each report.

Figure 50. Table. I-39 MM 24 site field measurements on January 11, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/16/2018
Location Site Number: 3
Location description: I-39 Minonk MM 24

Indigo Bush with/without Slated Snow Fence

Time start: 01/14/18 at 4:30PM
Time finish: 01/16/18 at 3:30 PM
Observer: Darrell Tiesman
Series of photos taken? No
Air temp: 1 - 25 degrees
Pavement temp: 5 - 25 degrees
Wind speed windward: 15 - 25 mph
Wind speed Leeward: 15 - 25 mph
Wind direction: SW and N
Snow Accumulation: 2 inches
Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	52	43	42		33	24		15		6	5	
Insert numbers for stake here	*	*	*		*	*		*		*	*	Slatted fence
	51	44	41	34	32	25	23	16	14	7	4	ROW Fence
Insert numbers for stake here	14"	16"	16"	14"	16"	24"	24"	22"	14"	21"	20"	
	50	45	40	35	31	26	22	17	13	8	3	
Insert numbers for stake here	32"	32"	36"	34"	31"	16"	20"	12"	17"	17"	17"	
	49	46	39	36	30	27	21	18	12	9	2	
Insert numbers for stake here	14"	12"	12"	12"	10"	20"	12"	8"	10"	17"	13"	
	48	47	38	37	29	28	20	19	11	10	1	
Insert numbers for stake here	12"	14"	14"	12"	10"	16"	12"	10"	10"	12"	12"	

Edge of roadway SB I-39

Other notes of importance: ALL MEASUREMENTS ARE IN INCHES. * = Missing stake.
Note: Actual local area weather information should be included with each report.

Figure 51. Table. I-39 MM 24 site field measurements on January 16, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date: 02/07/2018
Location Site Number: 3
Location description: I-39 Minonk MM 24

Indigo Bush with/without slated snow fence

Time start 12:31
Time finis 1:16
Observer: Cornwell
Series of photos taken? Y / N Yes
Air temp: 17F. El Paso
Pavement temp: 43.8 F
Wind speed windward:
Wind speed Leeward: 12-16 sustained
Wind direction: NW

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	52	43	42		33	24		15		6	5	
Insert numbers for stake here												Slatted fence
	51	44	41	34	32	25	23	16	14	7	4	ROW Fence
Insert numbers for stake here	12"	16"	16"	16"	13"	17"	14"	17"	14"	14"	12"	
	50	45	40	35	31	26	22	17	13	8	3	
Insert numbers for stake here	8"	10"	8"	9"	12"	6"	9"	6"	12"	10"	6"	
	49	46	39	36	30	27	21	18	12	9	2	
Insert numbers for stake here	8"	9"	8"	9"	9"	10"	8"	7"	8"	7"	8"	
	48	47	38	37	29	28	20	19	11	10	1	
Insert numbers for stake here	5"	6"	6"	7"	7"	4"	5"	5"	5"	6"	6"	
				sub drain outlet								

Edge of roadway SB I-39

Other notes of importance: Slats in fence run from column D to I. The first row could be affected by salty snow thrown from plows.
Let temperature gun and wind/temp guage equilibrate outside the vehicle while conducting tests. That said, not sure the temp guage actually was recording the right temp. Need to verify.
No stakes have been installed on the windward side of the ROW. No rebar and also concern for farmers.

Note: Actual local area weather information should be included with each report.

Note: Steps for recording information at each site
1. Set up all safety beacons, flashers, and reflective vests
2. Begin filling out paper spreadsheet copy for site
3. Take all necessary photos. I start by taking a photo from the middle of the right side of the site,
and then from the right to left between each two poles take a series of photos at the same location and height on the pavement shoulder.
4. Collect all measuring pole data following the numerical sequence on the grid.
5. Record all other necessary information on the sheet, including any important notes.

Figure 52. Table. I-39 MM 24 site field measurements on February 7, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/10/2019
Location Site Number: 3
Location description: I-39 Minonk MM 24

Single event in this winter season

Time start 11:40 AM
Time finis 12:00 PM
Observer: NA,DD
Series of photos taken? Y / N Y
Air temp: 23' F
Pavement temp:
Wind speed windward:
Wind speed Leeward: 7 mph
Wind direction: NW

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	52	43	42		33	24		15		6	5	
Insert numbers for stake here												Slatted fence
	51	44	41	34	32	25	23	16	14	7	4	ROW Fence
Insert numbers for stake here	5"	16"	16"	14"	18"	12"	11"	16"	12"	21"	13"	
	50	45	40	35	31	26	22	17	13	8	3	
Insert numbers for stake here	32"	12"	14"	12"	21"	12"	18"	9"	20"	10"	10"	
	49	46	39	36	30	27	21	18	12	9	2	
Insert numbers for stake here	12"	24"	11"	9"	10"	21"	15"	12"	13"	8"	14"	
	48	47	38	37	29	28	20	19	11	10	1	
Insert numbers for stake here	10"	8"	7"	5"	8"	12"	6"	9"	7"	6"	5"	

Edge of roadway SB I-39

Other notes of importance: no entry = no stake

Figure 53. Table. I-39 MM 24 site field measurements on January 10, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/05/2018
Location Site Number: 4
Location description: I-39 Minonk MM 24 south of site 3

Fragrant/Staghorn Sumac

Time start:
Time finish:
Observer: PAH,DD
Series of photos taken? Y / N
Air temp:
Pavement temp:
Wind speed windward:
Wind speed Leeward:
Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	52	43	42		33	24		15		6	5	
												ROW Fence
Insert numbers for stake here	51	44	41	34	32	25	23	16	14	7	4	
	40"	36"	36"	31"	30"	30"	21"	27"	30"	31"	24"	
Insert numbers for stake here	50	45	40	35	31	26	22	17	13	8	3	
	9"	10"	9"	12"	24"	22"	26"	24"	19"	18"	18"	
Insert numbers for stake here	49	46	39	36	30	27	21	18	12	9	2	
	9"	9"	9"	12"	9"	12"	14"	12"	12"	9"	9"	
Insert numbers for stake here	48	47	38	37	29	28	20	19	11	10	1	
	11"	12"	14"	12"	12"	14"	12"	12"	12"	14"	13"	
Insert numbers for stake here												

Edge of roadway SB I-39

Other notes of importance: no entry = no stake
Note: Actual local area weather information should be included with each report.

Figure 54. Table. I-39 MM 24 south site—3 field measurements on January 5, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/11/2018

Location Site Number: 4

Location description: I-39 Minonk MM 24 south of site 3

Fragrant/Staghorn Sumac

Time start: Base Line

Time finish:

Observer: Darrell Tiesman

Series of photos taken? No

Air temp: .

Pavement temp: .

Wind speed windward:

Wind speed Leeward:

Wind direction: .

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	52	43	42		33	24		15		6	5	
	*	*	*		*	*		*		*	*	Slatted fence
Insert numbers for stake here	51	44	41	34	32	25	23	16	14	7	4	ROW Fence
	12"	12"	3"	10"	10"	8"	2"	9"	12"	10"	8"	
Insert numbers for stake here	50	45	40	35	31	26	22	17	13	8	3	
	0"	0"	0"	0"	15"	1"	2"	2"	2"	1"	1"	
Insert numbers for stake here	49	46	39	36	30	27	21	18	12	9	2	
	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	
Insert numbers for stake here	48	47	38	37	29	28	20	19	11	10	1	
	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	
Insert numbers for stake here												

Edge of roadway SB I-39

Other notes of importance: *= Missing Stake

Note: Actual local area weather information should be included with each report.

Figure 55. Table. I-39 MM 24 south site—3 field measurements on January 11, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/16/2018
Location Site Number: 4
Location description: I-39 Minonk MM 24 south of site 3

Fragrant/Staghorn Sumac

Time start:	01/14/18 at 4:30 PM
Time finish:	01/16/18 at 3:30 PM
Observer:	Darrell Tiesman
Series of photos taken?	No
Air temp:	1 - 25 degrees
Pavement temp:	5 - 25 degrees
Wind speed windward:	15 - 25 mph
Wind speed Leeward:	15 - 25 mph
Wind direction:	SW and N
Snow Accumulation:	2 inches

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	52	43	42		33	24		15		6	5	
	*	*	*		*	*		*		*	*	ROW Fence
Insert numbers for stake here	51	44	41	34	32	25	23	16	14	7	4	
	36"	36"	36"	33"	30"	26"	20"	28"	28"	30"	24"	
Insert numbers for stake here	50	45	40	35	31	26	22	17	13	8	3	
	36"	30"	46"	36"	30"	27"	28"	26"	30"	30"	20"	
Insert numbers for stake here	49	46	39	36	30	27	21	18	12	9	2	
	12"	10"	9"	14"	12"	12"	28"	16"	14"	30"	28"	
Insert numbers for stake here	48	47	38	37	29	28	20	19	11	10	1	
	12"	10"	9"	14"	12"	12"	18"	14"	14"	18"	12"	
Insert numbers for stake here												

Edge of roadway SB I-39

Other notes of importance: ALL MEASUREMENTS ARE IN INCHES. **Gap in schrubs between Markers 34 and 25.** *= Missing Stake

Note: Actual local area weather information should be included with each report.

Figure 56. Table. I-39 MM 24 south site—3 field measurements on January 16, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date: 02/07/2018
Location Site Number: 4
Location description: I-39 Minonk MM 24 south of site 3

Fragrant/Staghorn Sumac

Time start 1:18
Time finis 1:36
Observer: Cornwell
Series of photos taken? Y / N Yes Partly cloudy
Air temp: 17 F. El Paso My device was registering 28 F but was dropping
Pavement temp:
Wind speed windward: 12
Wind speed Leeward: 12
Wind dire NW

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	Fragrant sumac Column d-g				Gap	Staghorn sumac to the right of column I						
	52	43	42		33	24		15		6	5	
	n/a	n/a	n/a		n/a	n/a		n/a		n/a	n/a	ROW Fence
Insert numbers for stake here	51	44	41	34	32	25	23	16	14	7	4	
	13"	13"	12"	11"	9"	9"	12"	10"	8"	24"	10"	
Insert numbers for stake here	50	45	40	35	31	26	22	17	13	8	3	
	6"	7"	8"	7"	6"	7"	7"	7"	5"	6"	8"	
Insert numbers for stake here	49	46	39	36	30	27	21	18	12	9	2	
	6"	6"	8"	10"	10"	10"	10"	10"	12"	7"	7"	
Insert numbers for stake here	48	47	38	37	29	28	20	19	11	10	1	
	5"	5"	6"	5"	7"	9"	5"	5"	4"	8"	7"	
Insert numbers for stake here												

Edge of roadway SB I-39

Other notes of importance: 8" corn stubble in adjacent field. Cattails in wet ditch had been mown.
Shot a video clip of snow blowing between gap of different sumac. This space had been planted with small Buckeye trees.

Note: Actual local area weather information should be included with each report.

Note: Steps for recording information at each site
1. Set up all safety beacons, flashers, and reflective vests
2. Begin filling out paper spreadsheet copy for site
3. Take all necessary photos. I start by taking a photo from the middle of the right side of the site,
and then from the right to left between each two poles take a series of photos at the same location and height on the pavement shoulder.
4. Collect all measuring pole data following the numerical sequence on the grid.
5. Record all other necessary information on the sheet, including any important notes.

Figure 57. Table. I-39 MM 24 south site—3 field measurements on February 7, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date:	**01/10/2019**	**Single event in this winter season**
Location Site Number: 4		
Location description: I-39 Minonk MM 24 south of site 3		
Time start	12:07 PM	
Time finis	12:30 PM	
Observer: NA,DD		
Series of photos taken? Y / N	Y	
Air temp: 23' F		
Pavement temp:		
Wind speed windward:		
Wind speed Leeward:	7 mph	
Wind direction:	NW	

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	52	43	42		33	24		15		6	5	
Insert numbers for stake here	51	44	41	34	32	25	23	16	14	7	4	ROW Fence
	19"	24"	24"	8"	18"	10"	12"	8"	9"	12"	8"	
Insert numbers for stake here	50	45	40	35	31	26	22	17	13	8	3	
	12"	12"	12"	16"	12"	7"	8"	6"	12"	9"	8"	
Insert numbers for stake here	49	46	39	36	30	27	21	18	12	9	2	
	9"	12"	10"	16"	24"	33"	32"	9"	11"	13"	9"	
Insert numbers for stake here	48	47	38	37	29	28	20	19	11	10	1	
	12"	12"	12"	9"	8"	15"	10"	10"	10"	10"	14"	
Insert numbers for stake here												

Edge of roadway SB I-39

Other notes of importance: no entry = no stake

Note: Actual local area weather information should be included with each report.

Figure 58. Table. I-39 MM 24 south site—3 field measurements on January 10, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/10/2019

Single event in this winter season

Location Site Number: 3 Check plot. This serves site 4 as well

Location description: I-39 Minonk MM 24 south of site 3

Time start 12:00 PM

Time finisl 12:07 PM

Observer: NA,DD

Series of photos taken? Y / N Y

Air temp: 23' F

Pavement temp:

Wind speed windward:

Wind speed Leeward:

Wind direction: NW

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

							ROW Fence
Insert numbers for stake here	21	20	13	12	5	4	
	7"	7"	7"	9"	10"	9"	
Insert numbers for stake here	22	19	14	11	6	3	
	7"	8"	2"	6"	6"	10"	
Insert numbers for stake here	23	18	15	10	7	2	
	7"	16"	9"	8"	11"	6"	
Insert numbers for stake here	24	17	16	9	8	1	
	5"	4"	7"	8"	7"	6"	
Insert numbers for stake here							
MM 24 sign							
			Edge of Southbound I-39				

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 59. Table. I-39 MM 24 south site—3 field measurements on January 10, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/05/2018 **Grey twig Dogwood**
Location Site Number: 2
Location description: I-55 Dwight MM222
Time start:
Time finish:
Observer: PAH,DD
Series of photos taken? Y / N n
Air temp:
Pavement temp:
Wind speed windward:
Wind speed Leeward:
Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	58		48		38	27		17		7	6	
Insert numbers for stake here												ROW Fence
	57		47		37	28		18		8	5	
Insert numbers for stake here												
	56	49	46	39	36	29	26	19	16	9	4	
Insert numbers for stake here	7"	10"			7"	8"	6"	6"	6"	10"	12"	
	55	50	45	40	35	30	25	20	15	10	3	
Insert numbers for stake here	9"	8"	10"	14"	10"	10"	13"	12"	14"	16"	15"	
	54	51	44	41	34	31	24	21	14	11	2	
Insert numbers for stake here	13"	12"	10"	14"	13"	11"	13"	14"	10"	10"	9"	
	53	52	43	42	33	32	23	22	13	12	1	
Insert numbers for stake here	14"	11"	15"	14"	13"	12"	13"	11"	13"	11"	12"	

Edge of roadway SB I-55

Other notes of importance: no entry = no stake
Note: Actual local area weather information should be included with each report.

Figure 60. Table. I-55 MM 222 field measurements on January 5, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date: **01/11/2018** | **Grey Twig Dogwood**

Location Site Number: 2

Location description: I-55 Dwight MM222

Time start:

Time finish: Base Line

Observer: Darrell Tiesman

Series of photos taken? No

Air temp:

Pavement temp:

Wind speed windward:

Wind speed Leeward:

Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	58		48		38	27		17		7	6
Insert numbers for stake here	*		*		*	*		*		*	*
ROW Fence											
	57		47		37	28		18		8	5
Insert numbers for stake here	*		*		*	*		*		*	*
	56	49	46	39	36	29	26	19	16	9	4
Insert numbers for stake here	0"	0"	*	*	0"	0"	0"	0"	0"	0"	0"
	55	50	45	40	35	30	25	20	15	10	3
Insert numbers for stake here	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"
	54	51	44	41	34	31	24	21	14	11	2
Insert numbers for stake here	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"
	53	52	43	42	33	32	23	22	13	12	1
Insert numbers for stake here	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"
Edge of roadway SB I-55											

Other notes of importance: . * = Missing stake.

Note: Actual local area weather information should be included with each report.

Figure 61. Table. I-55 MM 222 field measurements on January 11, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/16/2018 | **Grey Twig Dogwood**

Location Site Number: 2

Location description: I-55 Dwight MM222

Time start: 01/14/18 at 4:30 PM

Time finish: 01/16/18 at 3:30 PM

Observer: Darrell Tiesman

Series of photos taken? No

Air temp: 1 - 25 degrees

Pavement temp: 5 - 25 degress

Wind speed windward: 15 - 25 mph

Wind speed Leeward: 15 - 25 mph

Wind direction: SW and N

Snow Accumulation: 2 inches

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	58		48		38	27		17		7	6	
Insert numbers for stake here	*		*		*	*		*		*	*	ROW Fence
	57		47		37	28		18		8	5	
Insert numbers for stake here	*		*		*	*		*		*	*	
	56	49	46	39	36	29	26	19	16	9	4	
Insert numbers for stake here	8"	8"	*	*	8"	8"	6"	7"	10"	9"	12"	
	55	50	45	40	35	30	25	20	15	10	3	
Insert numbers for stake here	10"	11"	11"	12"	10"	10"	12"	11"	13"	9"	9"	
	54	51	44	41	34	31	24	21	14	11	2	
Insert numbers for stake here	15"	16"	16"	13"	12"	10"	12"	12"	10"	13"	7"	
	53	52	43	42	33	32	23	22	13	12	1	
Insert numbers for stake here	14"	14"	16"	14"	12"	11"	12"	13"	14"	12"	12"	

Edge of roadway SB I-55

Other notes of importance: ALL MEASUREMENTS ARE IN INCHES. * = Missing stake.

Note: Actual local area weather information should be included with each report.

Figure 62. Table. I-55 MM 222 field measurements on January 16, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/10/2019 — **Before Snowfall**

Location Site Number: 2

Location description: I-55 Dwight MM222

Time start: 9:15 AM

Time finish: 9:30 AM

Observer: NA,DD

Series of photos taken (insert file date and time xx/yy/zzzz xx:yy am or pm)

Air temp: 19' F

Pavement temp:

Wind speed Leeward: 9 mph

Wind direction: N

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Insert numbers for stake here

ROW Fence

	51		42		33	28		19		10	5
Insert numbers for stake here	5"		1"		3"	6"		2"		2"	5"
	50	46	41	37	32	27	23	18	14	9	4
Insert numbers for stake here	10"	8"	10"	5"	8"	7"	7"	7"	8"	7"	9"
	49	45	40	36	31	26	22	17	13	8	3
Insert numbers for stake here	10"	7"	11"	9"	9"	10"	12"	11"	11"	12"	4"
	48	44	39	35	30	25	21	16	12	7	2
Insert numbers for stake here	18"	12"	16"	8"	10"	11"	8"	10"	9"	8"	8"
	47	43	38	34	29	24	20	15	11	6	1
Insert numbers for stake here	11"	12"	12"	12"	7"	9"	6"	5"	7"	8"	6"

Edge of roadway SB I-55

Other notes of importance:

Pre-Storm Baseline

Note: Actual local area weather information should be included with each report.

Figure 63. Table. I-55 MM 222 field measurements on January 10, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: | **After Snowfall**

Location Site Number: 2

Location description: I-55 Dwight MM222

Time start:

Time finish:

Observer: NA,DD

Series of photos taken (insert file date and time xx/yy/zzzz xx:yy am or pm)

Air temp:

Pavement temp:

Wind speed Leeward:

Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Insert numbers for stake here												ROW Fence
	51		42		33	28		19		10	5	
Insert numbers for stake here	14"		7"		12"	5"		6"		7"	11"	
	50	46	41	37	32	27	23	18	14	9	4	
Insert numbers for stake here	9"	8"	9"	6"	9"	9"	9"	9"	11"	10"	12"	
	49	45	40	36	31	26	22	17	13	8	3	
Insert numbers for stake here	9"	10"	10"	10"	11"	11"	12"	12"	11"	15"	9"	
	48	44	39	35	30	25	21	16	12	7	2	
Insert numbers for stake here	13"	17"	13"	9"	9"	9"	9"	12"	10"	9"	11"	
	47	43	38	34	29	24	20	15	11	6	1	
Insert numbers for stake here	9"	7"	8"	10"	9"	8"	6"	7"	9"	8"	7"	

Edge of roadway SB I-55

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 64. Table. I-55 MM 222 field measurements.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/18/2019 | **Before Snowfall**

Location Site Number: 2

Location description: I-55 Dwight MM222

Time start: 9:00 AM

Time finish: 9:11 AM

Observer: JMK,DD

Series of photos taken (insert file date and time xx/yy/zzzz xx:yy am or pm)

Air temp: 31' F

Pavement temp:

Wind speed Leeward:

Wind direction: Calm

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Insert numbers for stake here	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	ROW Fence
	51		42		33	28		19		10	5	
Insert numbers for stake here	7"		2"		6"	8"		4"		5"	7"	
	50	46	41	37	32	27	23	18	14	9	4	
Insert numbers for stake here	8"	6"	8"	4"	7"	5"	6"	7"	9"	8"	9"	
	49	45	40	36	31	26	22	17	13	8	3	
Insert numbers for stake here	9"	7"	9"	9"	7"	8"	11"	10"	10"	12"	6"	
	48	44	39	35	30	25	21	16	12	7	2	
Insert numbers for stake here	15"	15"	12"	9"	6"	9"	7"	9"	8"	7"	11"	
	47	43	38	34	29	24	20	15	11	6	1	
Insert numbers for stake here	9"	6"	8"	7"	6"	7"	5"	6"	8"	6"	7"	

Edge of roadway SB I-55

Other notes of importance:

Pre-Storm Baseline

Note: Actual local area weather information should be included with each report.

Figure 65. Table. I-55 MM 222 field measurements on January 18, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/20/2019 **After Snowfall**
Location Site Number: 2
Location description: I-55 Dwight MM222
Time start: 3:22 PM
Time finish: 3:48 PM
Observer: JMK,NA
Series of photos taken (insert file date and time xx/yy/zzzz xx:yy am or pm) Y
Air temp: 11
Pavement temp:
Wind speed Leeward:
Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Insert numbers for stake here

- ROW Fence

	51		42		33	28		19		10	5
Insert numbers for stake here	13"		26"		26"	29"		16"		19"	16"
	50	46	41	37	32	27	23	18	14	9	4
Insert numbers for stake here	11"	11"	9"	12"	13"	20"	9"	30"	32"	33"	12"
	49	45	40	36	31	26	22	17	13	8	3
Insert numbers for stake here	8"	8"	9"	11"	12"	10"	11"	11"	9"	13"	8"
	48	44	39	35	30	25	21	16	12	7	2
Insert numbers for stake here	10"	10"	10"	8"	7"	8"	8"	10"	9"	6"	9"
	47	43	38	34	29	24	20	15	11	6	1
Insert numbers for stake here	7"	6"	8"	7"	6"	7"	5"	6"	8"	6"	6"

Edge of roadway SB I-55

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 66. Table. I-55 MM 222 field measurements on January 20, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/25/2019 **Before Snowfall**

Location Site Number: 2

Location description: I-55 Dwight MM222

Time start: 9:47a

Time finish: 10:15a

Observer: PAH,NA

Series of photos taken (insert file date and time xx/yy/zzzz xx:yy am or pm)

Air temp:

Pavement temp:

Wind speed Leeward:

Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Insert numbers for stake here

	51		42		33	28		19		10	5	ROW Fence
Insert numbers for stake here	10"		13"		24"	12"		14"		14"	11"	
	50	46	41	37	32	27	23	18	14	9	4	
Insert numbers for stake here	8"	8"	7"	10"	9"	15"	5"	20"	23"	20"	8"	
	49	45	40	36	31	26	22	17	13	8	3	
Insert numbers for stake here	6"	6"	7"	7"	6"	6"	9"	9"	7"	11"	5"	
	48	44	39	35	30	25	21	16	12	7	2	
Insert numbers for stake here	9"	6"	8"	5"	5"	7"	6"	8"	7"	5"	5"	
	47	43	38	34	29	24	20	15	11	6	1	
Insert numbers for stake here	7"	4"	6"	6"	5"	5"	3"	4"	6"	4"	4"	

Edge of roadway SB I-55

Other notes of importance:

Pre-Storm

Note: Actual local area weather information should be included with each report.

Figure 67. Table. -55 MM 222 field measurements on January 25, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/29/2019

After Snowfall

Location Site Number: 2

Location description: I-55 Dwight MM222

Time start:

Time finish:

Observer: PAH,NA

Series of photos taken (insert file date and time xx/yy/zzzz xx:yy am or pm)

Air temp:

Pavement temp:

Wind speed Leeward:

Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Insert numbers for stake here												ROW Fence
	51		42		33	28		19		10	5	
Insert numbers for stake here	24"		10"		12"	15"		15"		16"	15"	
	50	46	41	37	32	27	23	18	14	9	4	
Insert numbers for stake here	18"	9"	10"	12"	10"	28"	18"	26"	31"	42"	29"	
	49	45	40	36	31	26	22	17	13	8	3	
Insert numbers for stake here	12"	11"	11"	12"	17"	15"	12"	13"	12"	15"	11"	
	48	44	39	35	30	25	21	16	12	7	2	
Insert numbers for stake here	12"	11"	13"	8"	8"	9"	9"	12"	11"	10"	10"	
	47	43	38	34	29	24	20	15	11	6	1	
Insert numbers for stake here	14"	13"	13"	14"	14"	14"	12"	12"	14"	13"	10"	

Edge of roadway SB I-55

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 68. Table. I-55 MM 222 field measurements on January 29, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 02/01/2019
Location Site Number: 2
Location description: I-55 Dwight MM222
Time start: 10:30 AM
Time finish: 11:00 AM
Observer: DD,NA
Series of photos taken (insert file date and time xx/yy/zzzz xx:yy am or pm)
Air temp: 14
Pavement temp:
Wind speed Leeward: 4 mph
Wind direction: E

Depth are more than 01/29/2019 snow event

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Insert numbers for stake here	ROW Fence										
	51		42		33	28		19		10	5
Insert numbers for stake here	21"		20"		21"	15"		19"		18"	18"
	50	46	41	37	32	27	23	18	14	9	4
Insert numbers for stake here	18"	13"	12"	16"	12"	19"	21"	29"	34"	36"	31"
	49	45	40	36	31	26	22	17	13	8	3
Insert numbers for stake here	13"	12"	12"	13"	19"	17"	15"	16"	16"	18"	12"
	48	44	39	35	30	25	21	16	12	7	2
Insert numbers for stake here	15"	15"	13"	11"	12"	12"	12"	14"	14"	13"	11"
	47	43	38	34	29	24	20	15	11	6	1
Insert numbers for stake here	17"	15"	17"	16"	17"	16"	16"	16"	17"	15"	14"

Edge of roadway SB I-55

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 69. Table. I-55 MM 222 field measurements on February 1, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/10/2019 **Before Snowfall**

Location Site Number: 2--**Check site**

Location description: I-55 Dwight MM222

Time start: 9:30 AM

Time finish: 9:50 AM

Observer: NA,DD

Series of photos taken (please note date: xx/yy/zzzz and time xx:yy am or pm)

Air temp: 19' F

Pavement temp:

Wind speed Leeward: 5 mph

Wind direction: N NE

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

R.O.W Fence

		28		17		6
Insert numbers for stake here		12"		15"		7"
	33	27	22	16	11	5
Insert numbers for stake here	8"	4"	5"	5"	5"	4"
	32	26	21	15	10	4
Insert numbers for stake here	11"	9"	9"	7"	8"	3"
	31	25	20	14	9	3
Insert numbers for stake here	7"	9"	12"	8"	4"	5"
	30	24	19	13	8	2
Insert numbers for stake here	7"	7"	3"	4"	3"	5"
	29	23	18	12	7	1
Insert numbers for stake here	6"	3"	5"	5"	5"	6"

Edge of roadway SB I-55

Other notes of importance:

Pre Storm Baseline

Note: Actual local area weather information should be included with each report.

Figure 70. Table. I-55 MM 222 check site field measurements on January 10, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: | **After Snowfall**

Location Site Number: 2--**Check site**

Location description: I-55 Dwight MM222

Time start:

Time finish:

Observer:

Series of photos taken (please note date: xx/yy/zzzz and time xx:yy am or pm) Y

Air temp:

Pavement temp:

Wind speed Leeward:

Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

							R.O.W Fence
		28		17		6	
Insert numbers for stake here		13"		14"		12"	
	33	27	22	16	11	5	
Insert numbers for stake here	10"	8"	7"	8"	7"	10"	
	32	26	21	15	10	4	
Insert numbers for stake here	10"	14"	6"	10"	10"	7"	
	31	25	20	14	9	3	
Insert numbers for stake here	8"	8"	10"	9"	5"	4"	
	30	24	19	13	8	2	
Insert numbers for stake here	8"	11"	8"	8"	9"	7"	
	29	23	18	12	7	1	
Insert numbers for stake here	8"	6"	7"	6"	10"	7"	

Edge of roadway SB I-55

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 71. Table. I-55 MM 222 check site field measurements.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/18/2019 **Before Snowfall**

Location Site Number: 2--**Check site**

Location description: I-55 Dwight MM222

Time start: 9:11 AM

Time finish: 9:18 AM

Observer: JMK,DD

Series of photos taken (please note date: xx/yy/zzzz and time xx:yy am or pm)

Air temp: 31' F

Pavement temp:

Wind speed Leeward:

Wind direction: Calm

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

R.O.W Fence

		28		17		6
Insert numbers for stake here		12"		11"		10"
	33	27	22	16	11	5
Insert numbers for stake here	6"	5"	5"	6"	6"	7"
	32	26	21	15	10	4
Insert numbers for stake here	10"	10"	5"	8"	8"	5"
	31	25	20	14	9	3
Insert numbers for stake here	6"	8"	9"	9"	4"	4"
	30	24	19	13	8	2
Insert numbers for stake here	6"	7"	5"	6"	6"	5"
	29	23	18	12	7	1
Insert numbers for stake here	6"	5"	5"	4"	8"	5"

Edge of roadway SB I-55

Other notes of importance:

Pre Storm Baseline

Note: Actual local area weather information should be included with each report.

Figure 72. Table. I-55 MM 222 check site field measurements on January 18, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/20/2019

After Snowfall

Location Site Number: 2--**Check site**

Location description: I-55 Dwight MM222

Time start: 3:48p

Time finish: 4:00p

Observer: JMK,NA

Series of photos taken (please note date: xx/yy/zzzz and time xx:yy am or pm) Y

Air temp: 11' F

Pavement temp:

Wind speed Leeward:

Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

R.O.W Fence

		28		17		6
Insert numbers for stake here		12"		15"		22"
	33	27	22	16	11	5
Insert numbers for stake here	11"	16"	15"	12"	22"	34"
	32	26	21	15	10	4
Insert numbers for stake here	24"	13"	13"	11"	21"	8"
	31	25	20	14	9	3
Insert numbers for stake here	13"	9"	10"	11"	13"	3"
	30	24	19	13	8	2
Insert numbers for stake here	6"	10"	9"	10"	10"	6"
	29	23	18	12	7	1
Insert numbers for stake here	5"	5"	5"	5"	8"	5"

Edge of roadway SB I-55

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 73. Table. I-55 MM 222 check site field measurements on January 20, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/25/2019 **Before Snowfall**

Location Site Number: 2--**Check site**

Location description: I-55 Dwight MM222

Time start: 10:15 AM

Time finish: 10:22 AM

Observer: PAH,NA

Series of photos taken (please note date: xx/yy/zzzz and time xx:yy am or pm)

Air temp:

Pavement temp:

Wind speed Leeward:

Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	- - -	- - -	- - -	- - -	- - -	- - -	R.O.W Fence
		28		17		6	
Insert numbers for stake here		9"		12"		17"	
	33	27	22	16	11	5	
Insert numbers for stake here	15"	12"	11"	9"	15"	24"	
	32	26	21	15	10	4	
Insert numbers for stake here	20"	10"	9"	8"	15"	5"	
	31	25	20	14	9	3	
Insert numbers for stake here	10"	6"	7"	8"	9"	3"	
	30	24	19	13	8	2	
Insert numbers for stake here	5"	8"	7"	8"	6"	4"	
	29	23	18	12	7	1	
Insert numbers for stake here	4"	2"	4"	3"	5"	3"	

Edge of roadway SB I-55

Other notes of importance:

Pre-Storm

Note: Actual local area weather information should be included with each report.

Figure 74. Table. I-55 MM 222 check site field measurements on January 25, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/29/2019 **After Snowfall**

Location Site Number: 2--**Check site**

Location description: I-55 Dwight MM222

Time start:

Time finish:

Observer: PAH,NA

Series of photos taken (please note date: xx/yy/zzzz and time xx:yy am or pm)

Air temp:

Pavement temp:

Wind speed Leeward:

Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

R.O.W Fence

		28		17		6
Insert numbers for stake here		16"		14"		20"
	33	27	22	16	11	5
Insert numbers for stake here	19"	14"	11"	10"	14"	27"
	32	26	21	15	10	4
Insert numbers for stake here	21"	11"	10"	8"	16"	7"
	31	25	20	14	9	3
Insert numbers for stake here	10"	8"	9"	8"	10"	3"
	30	24	19	13	8	2
Insert numbers for stake here	7"	9"	8"	12"	19"	10"
	29	23	18	12	7	1
Insert numbers for stake here	12"	12"	11"	11"	11"	10"

Edge of roadway SB I-55

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 75. Table. I-55 MM 222 check site field measurements on January 29, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 02/01/2019

Location Site Number: 2--**Check site**

Depth are more than 01/29/2019 snow event

Location description: I-55 Dwight MM222

Time start: 11:00 AM

Time finish: 11:20 AM

Observer: DD,NA

Series of photos taken (please note date: xx/yy/zzzz and time xx:yy am or pm)

Air temp: 14' F

Pavement temp:

Wind speed Leeward: 4 mph

Wind direction: E

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

R.O.W Fence

		28		17		6
Insert numbers for stake here		18"		14"		21"
	33	27	22	16	11	5
Insert numbers for stake here	21"	18"	15"	14"	17"	29"
	32	26	21	15	10	4
Insert numbers for stake here	22"	16"	11"	12"	16"	10"
	31	25	20	14	9	3
Insert numbers for stake here	14"	11"	10"	12"	11"	6"
	30	24	19	13	8	2
Insert numbers for stake here	10"	11"	10"	17"	20"	13"
	29	23	18	12	7	1
Insert numbers for stake here	15"	13"	13"	14"	13"	14"

Edge of roadway SB I-55

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 76. Table. I-55 MM 222 check site field measurements on February 1, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/04/2018 **American Plum**

Location Site Number: 5

Location description: I-74 St. Joseph MM 193

Time start 8:30a

Time finis 8:50a

Observer: JMK, PAH

Series of photos taken? Y / N Y

Air temp: -4

Pavement temp:

Wind speed windward:

Wind speed Leeward:

Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	62	51					30	19	18	7	6	
Insert numbers for stake here	12"	8"					16"	15"	12"	15"	19"	
	61	52	50	41	40	31	29	20	17	8	5	ROW Fence
Insert numbers for stake here	7"	7"					12"	12"	8"	12"	9"	
	60	53	49	42	39	32	28	21	16	9	4	
Insert numbers for stake here	6"	5"	7"	7"	7"	7"	5"	6"	6"	11"	9"	
	59	54	48	43	38	33	27	22	15	10	3	
Insert numbers for stake here	9"	9"	9"	7"	12"	6"	6"	8"	11"	12"	12"	
	58	55	47	44	37	34	26	23	14	11	2	
Insert numbers for stake here	10"	9"	10"	12"	7"	9"	10"	8"	8"	11"	10"	
	57	56	46	45	36	35	25	24	13	12	1	
Insert numbers for stake here	8"	12"	9"	8"	10"	9"	9"	8"	12"	12"	12"	

Edge of roadway WB I-74

Other notes of importance: no entry = no stake

Note: Actual local area weather information should be included with each report.

Figure 77. Table. I-74 MM 193 field measurements on January 4, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date: **02/09/2018**

Location Site Number: 5

Location description: I-74 St. Joseph MM 193

American Plum

Time start: 10:20 AM

Time finish: 10:40 AM

Observer: JMK, PAH

Series of photos taken? Y / N Y

Air temp: 24

Pavement temp:

Wind speed windward:

Wind speed Leeward:

Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	62	51					30	19	18	7	6	
Insert numbers for stake here	4"	2"					4"	2"	8"	8"	3"	
	61	52	50	41	40	31	29	20	17	8	5	ROW Fence
Insert numbers for stake here	.5"	.5"	.5"	.5"	.5"	.5"	.5"	.5"	.5"	.5"	.5"	
	60	53	49	42	39	32	28	21	16	9	4	
Insert numbers for stake here	.5"	.5"	.5"	.5"	.5"	.5"	.5"	.5"	.5"	.5"	.5"	
	59	54	48	43	38	33	27	22	15	10	3	
Insert numbers for stake here	1"	1"	1"	1"	1"	1"	1"	1"	1"	1"	1"	
	58	55	47	44	37	34	26	23	14	11	2	
Insert numbers for stake here	2"	2"	2"	2"	2"	2"	2"	2"	2"	2"	2"	
	57	56	46	45	36	35	25	24	13	12	1	
Insert numbers for stake here	2"	2"	2"	2"	2"	2"	2"	2"	2"	2"	2"	

Edge of roadway WB I-74

Other notes of importance: Changed stake layout on spreadsheet to properly match field location.

Note: Actual local area weather information should be included with each report.

Figure 78. Table. I-74 MM 193 field measurements on January 4, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/10/2019 **Before Snowfall**

Location Site Number: 5

Location description: I-74 St. Joseph MM 193

Time start 1:30 PM

Time finis 1:55 PM

Observer: PAH,JMK

Series of photos taken? **Y** / N Y

Air temp: 29' F

Pavement temp:

Wind speed windward:

Wind speed Leeward: N/A

Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	58	47					30	19	18	7	6	ROW Fence
Insert numbers for stake here	2"	3"					4"	3"	3"	3"	4"	
	57	48					29	20	17	8	5	
Insert numbers for stake here	4"	4"					4"	4"	5"	6"	12"	
	56	49	46	39	38	31	28	21	16	9	4	
Insert numbers for stake here	4"	4"	4"	6"	6"	6"	3"	4"	4"	12"	11"	
	55	50	45	40	37	32	27	22	15	10	3	
Insert numbers for stake here	12"	14"	12"	7"	14"	6"	11"	12"	13"	18"	17"	
	54	51	44	41	36	33	26	23	14	11	2	
Insert numbers for stake here	12"	16"	15"	19"	12"	11"	15"	14"	12"	14"	17"	
	53	52	43	42	35	34	25	24	13	12	1	
Insert numbers for stake here	10"	14"	11"	12"	12"	12"	14"	12"	12"	20"	12"	

Edge of roadway WB I-74

Other notes of importance:

Pre-Storm Baseline, Grass ??

Note: Actual local area weather information should be included with each report.

Figure 79. Table. I-74 MM 193 field measurements on January 10, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/14/2019 **After Snowfall**
Location Site Number: 5
Location description: I-74 St. Joseph MM 193
Time start: 10:25 PM
Time finish: 11:00 AM
Observer: JMK, NA
Series of photos taken? Y / N Y
Air temp: 14' F
Pavement temp:
Wind speed windward:
Wind speed Leeward:
Wind direction: From North, Very Light

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	58	47					30	19	18	7	6	ROW Fence
Insert numbers for stake here	9"	8"					10"	13"	16"	27"	18"	
	57	48					29	20	17	8	5	
Insert numbers for stake here	10"	9"					10"	9"	9"	12"	14"	
	56	49	46	39	38	31	28	21	16	9	4	
Insert numbers for stake here	8"	9"	8"	10"	10"	8"	6"	8"	8"	16"	14"	
	55	50	45	40	37	32	27	22	15	10	3	
Insert numbers for stake here	18"	19"	17"	10"	16"	12"	13"	15"	16"	19"	18"	
	54	51	44	41	36	33	26	23	14	11	2	
Insert numbers for stake here	14"	17"	17"	20"	14"	13"	18"	16"	16"	18"	19"	
	53	52	43	42	35	34	25	24	13	12	1	
Insert numbers for stake here	14"	15"	14"	16"	15"	14"	17"	15"	15"	16"	14"	

Edge of roadway WB I-74

Other notes of importance:
Post-Strom No Blowing

Note: Actual local area weather information should be included with each report.

Figure 80. Table. I-74 MM 193 field measurements on January 14, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/18/2019

Before Snowfall

Location Site Number: 5

Location description: I-74 St. Joseph MM 193

Time start:

Time finish:

Observer: PAH,NA

Series of photos taken? Y / N

Air temp:

Pavement temp:

Wind speed windward:

Wind speed Leeward:

Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	58	47					30	19	18	7	6	ROW Fence
Insert numbers for stake here	6"	5"					7"	9"	11"	18"	10"	
	57	48					29	20	17	8	5	
Insert numbers for stake here	7"	7"					6"	6"	6"	8"	9"	
	56	49	46	39	38	31	28	21	16	9	4	
Insert numbers for stake here	5"	5"	6"	7"	7"	5"	4"	5"	4"	12"	9"	
	55	50	45	40	37	32	27	22	15	10	3	
Insert numbers for stake here	13"	13"	11"	8"	12"	7"	9"	10"	14"	15"	12"	
	54	51	44	41	36	33	26	23	14	11	2	
Insert numbers for stake here	10"	12"	11"	16"	9"	11"	15"	14"	10"	12"	13"	
	53	52	43	42	35	34	25	24	13	12	1	
Insert numbers for stake here	9"	12"	10"	12"	10"	10"	14"	10"	10"	12"	11"	

Edge of roadway WB I-74

Other notes of importance:

Pre-Storm Baseline

Note: Actual local area weather information should be included with each report.

Figure 81. Table. I-74 MM 193 field measurements on January 18, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/20/2019 **After Snowfall**
Location Site Number: 5
Location description: I-74 St. Joseph MM 193
Time start: 1:30p
Time finish: 1:47p
Observer: PAH,DD
Series of photos taken? Y / N Y
Air temp: 11' F
Pavement temp:
Wind speed windward:
Wind speed Leeward:
Wind direction: 14 NW

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	58	47					30	19	18	7	6	ROW Fence
Insert numbers for stake here	6"	6"					7"	10"	12"	21"	16"	
	57	48					29	20	17	8	5	
Insert numbers for stake here	21"	12"					16"	12"	13"	26"	15"	
	56	49	46	39	38	31	28	21	16	9	4	
Insert numbers for stake here	7"	9"	9"	9"	9"	6"	9"	5"	15"	14"	12"	
	55	50	45	40	37	32	27	22	15	10	3	
Insert numbers for stake here	23"	18"	17"	18"	22"	19"	20"	19"	16"	16"	15"	
	54	51	44	41	36	33	26	23	14	11	2	
Insert numbers for stake here	12"	17"	20"	17"	10"	21"	21"	15"	16"	17"	14"	
	53	52	43	42	35	34	25	24	13	12	1	
Insert numbers for stake here	14"	12"	11"	14"	12"	12"	14"	13"	12"	15"	14"	

Edge of roadway WB I-74

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 82. Table. I-74 MM 193 field measurements on January 20, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/10/2019 **Before Snowfall**

Location Site Number: 5 Check plot

Location description: I-74 St. Joseph MM 193 about a .1 mile west of existing site

Time start: 1:55 PM

Time finish: 2:05 PM

Observer:

Series of photos taken? Y / N Y

Air temp: 29' F

Pavement temp: N/A

Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	30	25	20	15	10	5	ROW Fence
Insert numbers for stake here	3"	10"	8"	4"	3"	4"	
	29	24	19	14	9	4	
Insert numbers for stake here	6"	3"	9"	4"	3"	3"	
	28	23	18	13	8	3	
Insert numbers for stake here	6"	4"	4"	3"	2"	2"	
	27	22	17	12	7	2	
Insert numbers for stake here	6"	5"	6"	8"	3"	4"	
	26	21	16	11	6	1	
Insert numbers for stake here	3"	5"	3"	4"	5"	4"	

Other notes of importance:

Pre-Storm Baseline, Grass ??

Note: Actual local area weather information should be included with each report.

Figure 83. Table. I-74 MM 193 check field measurements on January 10, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/14/2019 **After Snowfall**

Location Site Number: 5 Check plot

Location description: I-74 St. Joseph MM 193 about a .1 mile west of existing site

Time start: 11:03 AM

Time finish: 11:13 AM

Observer: JMK, NA

Series of photos taken? Y / N Y

Air temp: 14' F

Pavement temp:

Wind direction: North Wind, Very Light

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	30	25	20	15	10	5	ROW Fence
Insert numbers for stake here	9"	13"	14"	9"	8"	8"	
	29	24	19	14	9	4	
Insert numbers for stake here	11"	6"	14"	10"	9"	8"	
	28	23	18	13	8	3	
Insert numbers for stake here	11"	9"	10"	8"	8"	8"	
	27	22	17	12	7	2	
Insert numbers for stake here	9"	10"	11"	12"	8"	9"	
	26	21	16	11	6	1	
Insert numbers for stake here	10"	9"	8"	10"	10"	8"	

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 84. Table. I-74 MM 193 check field measurements on January 14, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/18/2019 — **Before Snowfall**

Location Site Number: 5 Check plot

Location description: I-74 St. Joseph MM 193 about a .1 mile west of existing site

Time start:

Time finish:

Observer:

Series of photos taken? Y / N Y

Air temp:

Pavement temp:

Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	30	25	20	15	10	5	ROW Fence
Insert numbers for stake here	6"	8"	10"	5"	4"	5"	
	29	24	19	14	9	4	
Insert numbers for stake here	8"	4"	9"	6"	7"	6"	
	28	23	18	13	8	3	
Insert numbers for stake here	7"	7"	6"	5"	5"	5"	
	27	22	17	12	7	2	
Insert numbers for stake here	7"	7"	7"	8"	6"	7"	
	26	21	16	11	6	1	
Insert numbers for stake here	7"	5"	6"	5"	8"	5"	

Other notes of importance:

Pre-Storm Baseline

Note: Actual local area weather information should be included with each report.

Figure 85. Table. I-74 MM 193 check field measurements on January 18, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/20/2019 — **After Snowfall**

Location Site Number: 5 Check plot

Location description: I-74 St. Joseph MM 193 about a .1 mile west of existing site

Time start: 1:50p

Time finish: 2:00p

Observer: PAH,DD

Series of photos taken? Y / N Y

Air temp: 11' F

Pavement temp:

Wind direction: 14 NW

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

ROW Fence

	30	25	20	15	10	5
Insert numbers for stake here	13"	10"	4"	7"	7"	6"
	29	24	19	14	9	4
Insert numbers for stake here	10"	6"	10"	11"	8"	7"
	28	23	18	13	8	3
Insert numbers for stake here	9"	8"	11"	6"	9"	6"
	27	22	17	12	7	2
Insert numbers for stake here	8"	7"	10"	10"	7"	7"
	26	21	16	11	6	1
Insert numbers for stake here	12"	9"	7"	9"	10"	9"

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 86. Table. I-74 MM 193 check field measurements on January 20, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/05/2018
Location Site Number: 7
Location description: I-72 MM 110 East of Dawson

Heavy Stand of Oak with Prairie Grass

Time start:
Time finish:
Observer: PAH,DD
Series of photos taken? Y / N n
Air temp:
Pavement temp:
Wind speed windward:
Wind speed Leeward:
Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Frontage Road

Overhead Power Line
ROW Fence

Note: Line of trees removed for power line clearance →

	54	43				25				7	6
	6"	7"				9"				6"	8"
	53	44				26				8	5
Insert numbers for stake here	5"	5"				3"				4"	4"
	52	45	42	35	34	27	24	17	16	9	4
Insert numbers for stake here	6"	0"	6"	5"	3"	5"	5"	0"	0"	0"	0"
	51	46	41	36	33	28	23	18	15	10	3
Insert numbers for stake here	5"	4"	6"	5"	6"	6"	7"	7"	5"	0	6"
	50	47	40	37	32	29	22	19	14	11	2
Insert numbers for stake here	5"	8"	7"	5"	5"	4"	8"	7"	6"	4"	5"
	49	48	39	38	31	30	21	20	13	12	1
Insert numbers for stake here	7"	8"	6"	8"	8"	8"	6"	7"	5"	5"	9"

Edge of roadway WB I-72

Other notes of importance:
Note: Actual local area weather information should be included with each report.

Figure 87. Table. I-72 MM 110 field measurements on January 5, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date: 12.30.2017
Location Site Number: 7
Location description: I-72 MM 110 East of Dawson

Snow Fall Ev Event: 12.29.2017

Heavy stand of Oak with Prairie grass

Time start 12.40 PM
Time finis 01.12 PM
Observer: Imran,Pranesh
Series of photos taken? Y / N YES
Air temp: 8-12 F
Pavement temp: (-10) to (-15) F
Wind speed windward: 5-9 mph
Wind speed Leeward: 5-9 mph
Wind direction: N TO SE

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Frontage Road

Overhead Power Line
ROW Fence

Note: Line of trees removed for power line clearance →

	54	43				25			A	7	6
	0"	0"				0"			0"	0"	*
	53	44				26			B	8	5
Insert numbers for stake here	0"	0"				0"			1"	0"	*
	52	45	42	35	34	27	24	17	16	9	4
Insert numbers for stake here	0"	1"	1"	0"	1"	0"	0"	0"	0"	0"	0"
	51	46	41	36	33	28	23	18	15	10	3
Insert numbers for stake here	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"
	50	47	40	37	32	29	22	19	14	11	2
Insert numbers for stake here	0"	0"	1"	0"	0"	0"	0"	0"	1"	0"	0"
	49	48	39	38	31	30	21	20	13	12	1
Insert numbers for stake here	0"	0"	0"	0"	0"	0"	1"	0"	0"	0"	0"

Edge of roadway WB I-72

Other notes of importance:
NOTES: A and B Stake Found at Site, * = NO STAKE

Figure 88. Table. I-72 MM 110 field measurements on December 30, 2017.

Living Snow Fence Field Measurement Spreadsheet

Date: **01/10/2019**
Location Site Number: 7
Location description: **I-72 MM 110 East of Dawson**
Time start **11:00 AM**
Time finish **11:30 AM**
Observer: **Mohiuddin Imran and Al-Adib Sarker**
Series of photos taken? Y / N **Yes**
Air temp: **23 F**
Pavement temp: **23 F**
Wind speed windward: **5 mph**
Wind speed Leeward: **3 mph**
Wind direction: **NE**

Prior Snowfall

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Frontage Road

Overhead Power Line

ROW Fence

Note: Line of trees removed for power line clearance →	54	43				25				7	6
	5"	4"				7"			5"	6"	
	53	44				26				8	5
Insert numbers for stake here	3"	5"				2"			2"	2"	
	52	45	42	35	34	27	24	17	16	9	4
Insert numbers for stake here	6"	4"	6"	4"	2"	3"	4"	4"	3"	5"	3"
	51	46	41	36	33	28	23	18	15	10	3
Insert numbers for stake here	5"	5"	7"	4"	7"	6"	4"	7"	2"	5"	4"
	50	47	40	37	32	29	22	19	14	11	2
Insert numbers for stake here	5"	6"	4"	5"	6"	5"	6"	8"	5"	5"	4"
	49	48	39	38	31	30	21	20	13	12	1
Insert numbers for stake here	6"	5"	X	5"	8"	7"	5"	X	4"	5"	X

Edge of roadway WB I-72

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 89. Table. I-72 MM 110 field measurements on January 10, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: **01/13/2019**

After Snowfall

Location Site Number: 7

Location description: **I-72 MM 110 East of Dawson**

Time start **2:00 PM**

Time finish **2:30 PM**

Observer: **Mohiuddin Imran and Al-Adib Sarker**

Series of photos taken? Y / N **Yes**

Air temp: **28 F**

Pavement temp: **28 F**

Wind speed windward: **29 mph**

Wind speed Leeward: **20 mph**

Wind direction: **NE**

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Frontage Road

Overhead Power Line

ROW Fence

Note: Line of trees removed for power line clearance →

	54	43				25				7	6
	12"	12"				14"			13"	13"	
	53	44				26				8	5
Insert numbers for stake here	10"	11"				10"			10"	10"	
	52	45	42	35	34	27	24	17	16	9	4
Insert numbers for stake here	11"	10"	11"	11"	10"	8"	10"	12"	9"	12"	12"
	51	46	41	36	33	28	23	18	15	10	3
Insert numbers for stake here	11"	11"	12"	10"	13"	13"	10"	13"	10"	11"	12"
	50	47	40	37	32	29	22	19	14	11	2
Insert numbers for stake here	11"	12"	11"	10"	11"	9"	11"	13"	12"	12"	10"
	49	48	39	38	31	30	21	20	13	12	1
Insert numbers for stake here	11"	12"	X	10"	13"	14"	11"	X	9"	12"	X

Edge of roadway WB I-72

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 90. Table. I-72 MM 110 field measurements on January 13, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: **01/17/2019**
Location Site Number: 7
Location description: **I-72 MM 110 East of Dawson**
Time start **12:30 PM**
Time finish **1:00 PM**
Observer: **Mohiuddin Imran and Al-Adib Sarker**
Series of photos taken? Y / N **Yes**
Air temp: **35 F**
Pavement temp: **35 F**
Wind speed windward: **7 mph**
Wind speed Leeward: **3 mph**
Wind direction: **NNW**

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Frontage Road

Overhead Power Line
ROW Fence

Note: Line of trees removed for power line clearance →	54	43				25				7	6
	12"	6"				10"			10"	9"	
	53	44				26				8	5
Insert numbers for stake here	8"	6"				4"			5"	6"	
	52	45	42	35	34	27	24	17	16	9	4
Insert numbers for stake here	7"	5"	7"	7"	5"	5"	5"	7"	5"	7"	6"
	51	46	41	36	33	28	23	18	15	10	3
Insert numbers for stake here	7"	6"	8"	5"	9"	6"	6"	9"	5"	7"	7"
	50	47	40	37	32	29	22	19	14	11	2
Insert numbers for stake here	6"	9"	6"	6"	6"	5"	6"	9"	8"	8"	6"
	49	48	39	38	31	30	21	20	13	12	1
Insert numbers for stake here	7"	8"	X	7"	11"	12"	7"	X	7"	8"	X

Edge of roadway WB I-72

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 91. Table. I-72 MM 110 field measurements on January 17, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/18/2019
Location Site Number: 7
Location description: I-72 MM 110 East of Dawson
Time start:
Time finish:
Observer:
Series of photos taken? Y / N
Air temp:
Pavement temp:
Wind speed windward:
Wind speed Leeward:
Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Frontage Road

Overhead Power Line
ROW Fence

Note: Line of trees removed for power line clearance →	54	43				25			16	5	
	8"	6"				10"			8"	9"	
	53	44				26			15	6	
Insert numbers for stake here	6"	6"				4"			5"	6"	
	52	45	42	35	34	27	24	17	14	7	4
Insert numbers for stake here	7"	7"	8"	7"	6"	6"	6"	8"	6"	8"	7"
	51	46	41	36	33	28	23	18	13	8	3
Insert numbers for stake here	7"	6"	8"	6"	9"	7"	6"	10"	5"	7"	7"
	50	47	40	37	32	29	22	19	12	9	2
Insert numbers for stake here	6"	10"	7"	6"	6"	6"	6"	9"	8"	8"	6"
	49	48	39	38	31	30	21	20	11	10	1
Insert numbers for stake here	7"	8"	X	7"	11"	11"	7"	X	7"	7"	X

Edge of roadway WB I-72

Other notes of importance:

Pre-Storm Baseline

Note: Actual local area weather information should be included with each report.

Figure 92. Table. I-72 MM 110 field measurements on January 18, 2019.

Living Snow Fence Field Measurement Spreadsheet								
Date: **01/10/2019**					**Before Snowfall**			
Location Site Number: 7--Check Plot								
Location description: **I-72 MM 111 East of Dawson**								
Time start **11:00 AM**								
Time finis **11:30 AM**								
Observer: **Mohiuddin Imran and Al-Adib Sarker**								
Series of photos taken? Y / N		**Yes**						
Air temp:	**23 F**							
Pavement temp:	**23 F**							
Wind speed Leeward:	**3 mph**							
Wind direction:	**NE**							
Fill in each measurement to the foot and closest inch for each measuring pole								
Yellow grids indicate a field stake								
			Frontage Road					
								ROW Fence
		24	20	16	12	8	4	
Insert numbers for stake here		2"	5"	4"	4"	0"	0"	
		23	19	15	11	7	3	
Insert numbers for stake here		1"	6"	4"	6"	1"	1"	
		22	18	14	10	6	2	
Insert numbers for stake here		2"	5"	6"	2"	1"	3"	
		21	17	13	9	5	1	
Insert numbers for stake here		3"	3"	3"	3"	1"	1"	
				Edge of roadway WB I-72				
Other notes of importance:								
Note: Actual local area weather information should be included with each report.								

Figure 93. Table. I-72 MM 110 check field measurements on January 10, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: **01/13/2019** **After Snowfall**

Location Site Number: 7--Check Plot

Location description: **I-72 MM 111 East of Dawson**

Time start **2:00 PM**

Time finis **2:30 PM**

Observer: **Mohiuddin Imran and Al-Adib Sarker**

Series of photos taken? Y / N **Yes**

Air temp: **28 F**

Pavement temp: **28 F**

Wind speed Leeward: **20 mph**

Wind direction: **NE**

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Frontage Road

ROW Fence

	24	20	16	12	8	4
Insert numbers for stake here	14''	18''	15''	22''	19''	8''
	23	19	15	11	7	3
Insert numbers for stake here	11''	11''	12''	12''	11''	11''
	22	18	14	10	6	2
Insert numbers for stake here	7''	10''	10''	7''	11''	12''
	21	17	13	9	5	1
Insert numbers for stake here	10''	9''	10''	9''	9''	11''

Edge of roadway WB I-72

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 94. Table. I-72 MM 110 check field measurements on January 13, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: **01/17/2019**
Location Site Number: 7--Check Plot
Location description: **I-72 MM 111 East of Dawson**
Time start **12:30 PM**
Time finis **1:00 PM**
Observer: **Mohiuddin Imran and Al-Adib Sarker**
Series of photos taken? Y / N **Yes**
Air temp: **35 F**
Pavement temp: **35 F**
Wind speed Leeward: **3 mph**
Wind direction: **NNW**

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Frontage Road

ROW Fence

	24	20	16	12	8	4
Insert numbers for stake here	12"	12"	9"	14"	13"	4"
	23	19	15	11	7	3
Insert numbers for stake here	6"	6"	6"	7"	6"	7"
	22	18	14	10	6	2
Insert numbers for stake here	4"	7"	5"	4"	6"	7"
	21	17	13	9	5	1
Insert numbers for stake here	7"	7"	7"	7"	7"	6"

Edge of roadway WB I-72

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 95. Table. I-72 MM 110 check field measurements on January 17, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/18/2019
Location Site Number: 7--Check Plot
Location description: I-72 MM 111 East of Dawson
Time start:
Time finish:
Observer:
Series of photos taken? Y / N
Air temp:
Pavement temp:
Wind speed Leeward:
Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Frontage Road

ROW Fence

	24	20	16	12	8	4
Insert numbers for stake here	10"	10"	8"	12"	11"	5"
	23	19	15	11	7	3
Insert numbers for stake here	5"	5"	7"	6"	6"	6"
	22	18	14	10	6	2
Insert numbers for stake here	4"	7"	5"	5"	3"	6"
	21	17	13	9	5	1
Insert numbers for stake here	7"	7"	7"	6"	7"	6"

Edge of roadway WB I-72

Other notes of importance:

Pre-Storm Baseline

Note: Actual local area weather information should be included with each report.

Figure 96. Table. I-72 MM 110 check field measurements on January 18, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/05/2018
Location Site Number: 6
Location description: I-72 MM 127 West of Niantic exit

Washington Hawthorne with Sand Bar Willow

Time start:
Time finish:
Observer: PAH,DD
Series of photos taken? Y / N n
Air temp:
Pavement temp:
Wind speed windward:
Wind speed Leeward:
Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	52	43	42		33	24		15		6	5	
Insert numbers for stake here										1"	1"	
	51	44	41	34	32	25	23	16	14	7	4	ROW Fence
Insert numbers for stake here	10"	8"	10"	4"	4"	5"	X	1"	1"	1"	4"	
	50	45	40	35	31	25	22	17	13	8	3	
Insert numbers for stake here	8"	5"	8"	6"	1"	1"	0	6"	8"	7"	9"	
	49	46	39	36	30	27	21	18	12	9	2	
Insert numbers for stake here	8"	8"	6"	8"	9"	9"	6"	8"	8"	8"	11"	
	48	47	38	37	29	28	20	19	11	10	1	
Insert numbers for stake here	7"	4"	6"	6"	6"	6"	6"	6"	8"	8"	7"	

Edge of roadway WB I-72

Other notes of importance: no entry = no stake
Note: Actual local area weather information should be included with each report.

Figure 97. Table. I-72 MM 127 field measurements on January 5, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date: 12.29.2017

Location Site Number: 6

Location description: I-72 MM 127 West of Niantic exit

Washington Hawthorne with Sand Bar Willow

Time start: 1.00 PM

Time finish: 1.45 PM

Observer: Imran, Pranesh

Series of photos taken? Y / N YES

Air temp: 8-12 F

Pavement temp: (-29) to (-33) F

Wind speed windward: 6-12 mph

Wind speed Leeward: 5-10 mph

Wind direction: W TO E

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	52	43	42		33	24		15		6	5	
Insert numbers for stake here	*	*	*		*	*		*		0''	0''	
	51	44	41	34	32	25	23	16	14	7	4	ROW Fence
Insert numbers for stake here	0''	0''	0''	0''	0''	0''	*	0''	1''	1''	0''	
	50	45	40	35	31	25	22	17	13	8	3	
Insert numbers for stake here	0''	0''	0''	1''	1''	0''	0''	0''	1''	0''	0''	
	49	46	39	36	30	27	21	18	12	9	2	
Insert numbers for stake here	0''	0''	0''	0''	1''	0''	0''	0''	0''	0''	0''	
	48	47	38	37	29	28	20	19	11	10	1	
Insert numbers for stake here	0''	0''	0''	0''	0''	0''	0''	0''	0''	0''	0''	

Edge of roadway WB I-72

Other notes of importance: NOTES * = NO STAKE

Note: Actual local area weather information should be included with each report.

Figure 98. Table. I-72 MM 127 field measurements on December 29, 2017.

Living Snow Fence Field Measurement Spreadsheet

Date: **01/10/2019** | **Before Snowfall**

Location Site Number: 6

Location description: **I-72 MM 127 West of Niantic exit**

Time start **10:30 AM**

Time finis **11:00 AM**

Observer: **Mohiuddin Imran and Al-Adib Sarker**

Series of photos taken? Y / N **Yes**

Air temp: **21 F**

Pavement temp: **21 F**

Wind speed windward: **5mph**

Wind speed Leeward: **0 mph**

Wind direction: **N**

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

										*	*	
										1''	1''	
	44	40	36	32	28	24	20	16	12	8	4	ROW Fence
Insert numbers for stake here	6''	6''	11''	3''	1''	4''	X	6''	3''	2''	2''	
	43	39	35	31	27	23	19	15	11	7	3	
Insert numbers for stake here	5''	0''	4''	5''	12''	8''	3''	4''	4''	3''	4''	
	42	38	34	30	26	22	18	14	10	6	2	
Insert numbers for stake here	4''	5''	4''	5''	6''	8''	6''	5''	6''	6''	5''	
	41	37	33	29	25	21	17	13	9	5	1	
Insert numbers for stake here	4''	2''	2''	2''	2''	3''	2''	3''	3''	3''	2''	

Edge of roadway WB I-72

Other notes of importance: no entry = no stake

Note: Actual local area weather information should be included with each report.

Figure 99. Table. I-72 MM 127 field measurements on January 10, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: **01/13/2019** | **After Snowfall**

Location Site Number: 6

Location description: **I-72 MM 127 West of Niantic exit**

Time start **1:30 PM**

Time finis **2:00 PM**

Observer: **Mohiuddin Imran and Al-Adib Sarker**

Series of photos taken? Y / N **Yes**

Air temp: **27 F**

Pavement temp: **27 F**

Wind speed windward: **15 mph**

Wind speed Leeward: **8 mph**

Wind direction: **NNE**

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

										*	*	
										11''	7''	
	44	40	36	32	28	24	20	16	12	8	4	ROW Fence
Insert numbers for stake here	24''	24''	16''	16''	12''	21''	X	12''	8''	8''	11''	
	43	39	35	31	27	23	19	15	11	7	3	
Insert numbers for stake here	12''	8''	12''	13''	17''	14''	10''	10''	12''	9''	12''	
	42	38	34	30	26	22	18	14	10	6	2	
Insert numbers for stake here	12''	13''	13''	15''	13''	14''	13''	12''	12''	13''	11''	
	41	37	33	29	25	21	17	13	9	5	1	
Insert numbers for stake here	11''	8''	8''	8''	9''	9''	8''	8''	9''	9''	9''	

Edge of roadway WB I-72

Other notes of importance: no entry = no stake

Note: Actual local area weather information should be included with each report.

Figure 100. Table. I-72 MM 127 field measurements on January 13, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: **01/17/2019**
Location Site Number: 6
Location description: **I-72 MM 127 West of Niantic exit**
Time start **11:30 AM**
Time finis **12:00 PM**
Observer: **Mohiuddin Imran and Al-Adib Sarker**
Series of photos taken? Y / N **Yes**
Air temp: **35 F**
Pavement **35 F**
Wind speed windward: **0 mph**
Wind speed Leeward: **0 mph**
Wind direction: **CALM**

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

										*	*	
										7"	4"	
	44	40	36	32	28	24	20	16	12	8	4	ROW Fence
Insert numbers for stake here	18"	18"	13"	11"	7"	15"	X	8"	5"	4"	6"	
	43	39	35	31	27	23	19	15	11	7	3	
Insert numbers for stake here	8"	4"	9"	8"	13"	9"	5"	6"	8"	4"	8"	
	42	38	34	30	26	22	18	14	10	6	2	
Insert numbers for stake here	9"	9"	9"	12"	10"	12"	8"	7"	7"	10"	9"	
	41	37	33	29	25	21	17	13	9	5	1	
Insert numbers for stake here	7"	5"	5"	6"	6"	6"	4"	4"	5"	5"	5"	

Edge of roadway WB I-72

Other notes of importance: no entry = no stake

Note: Actual local area weather information should be included with each report.

Figure 101. Table. I-72 MM 127 field measurements on January 17, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/18/2019
Location Site Number: 6
Location description: I-72 MM 127 West of Niantic exit
Time start: 8:48a
Time finish: 9:05a
Observer: PAH, NA
Series of photos taken? Y / N Y
Air temp: 28
Pavement temp:
Wind speed windward:
Wind speed Leeward:
Wind direction: Calm

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

									6	5	ROW FENCE
									6"	4"	
	46	39	38	31	30	23	22	15	14	7	4
Insert numbers for stake here	18"	18"	13"	10"	7"	14"	X	8"	5"	3"	6"
	45	40	37	32	29	24	21	16	13	8	3
Insert numbers for stake here	8"	4"	9"	8"	14"	10"	6"	5"	8"	4"	7"
	44	41	36	33	28	25	20	17	12	9	2
Insert numbers for stake here	8"	9"	7"	10"	9"	10"	9"	8"	8"	9"	9"
	43	42	35	34	27	26	19	18	11	10	1
Insert numbers for stake here	7"	5"	5"	6"	6"	6"	5"	4"	5"	6"	5"

Edge of roadway WB I-72

Other notes of importance:

Pre-Storm Baseline

Note: Actual local area weather information should be included with each report.

Figure 102. Table. I-72 MM 127 check field measurements on January 18, 2019.

Living Snow Fence Field Measurement Spreadsheet										
Date:	**01/10/2019**				**Before Snowfall**					
Location Site Number: 6 Check Plot										
Location description: **I-72 MM 127 West of Niantic exit**										
Time start:	**10:30 AM**									
Time finish:	**11:00 AM**									
Observer:	**Mohiuddin Imran and Al-Adib Sarker**									
Series of photos taken? Y / N			**Yes**							
Air temp:		**21 F**								
Pavement temp:		**21 F**								
Wind speed Leeward:		**0 mph**								
Wind direction:		**N**								
Fill in each measurement to the foot and closest inch for each measuring pole										
Yellow grids indicate a field stake										
Insert numbers for stake here										
			63	59	55	44	41	37	ROW Fence	
Insert numbers for stake here			1"	1"	0"					
			62	58	54	45	40	36		
Insert numbers for stake here			1"	1"	0"					
			61	57	53	46	39	35		
Insert numbers for stake here			1"	3"	0"					
			60	56	52	47	38	34		
Insert numbers for stake here			1"	1"	1"					
				Edge of West bound I-72						
Other notes of importance:										
Note: Actual local area weather information should be included with each report.										

Figure 103. Table. I-72 MM 127 check field measurements on January 10, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: **01/13/2019** After Snowfall
Location Site Number: 6 Check Plot
Location description: **I-72 MM 127 West of Niantic exit**
Time start: **1:30 PM**
Time finish: **2:00 PM**
Observer: **Mohiuddin Imran and Al-Adib Sarker**
Series of photos taken? Y / N **Yes**
Air temp: **27 F**
Pavement temp: **27 F**
Wind speed Leeward: **8 mph**
Wind direction: **NNE**

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Insert numbers for stake here							
	63	59	55	44	41	37	ROW Fence
Insert numbers for stake here	17"	19"	20"				
	62	58	54	45	40	36	
Insert numbers for stake here	12"	11"	12"				
	61	57	53	46	39	35	
Insert numbers for stake here	9"	11"	8"				
	60	56	52	47	38	34	
Insert numbers for stake here	8"	8"	10"				

Edge of West bound I-72

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 104. Table. I-72 MM 127 check field measurements on January 13, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/17/2019
Location Site Number: 6 Check Plot
Location description: I-72 MM 127 West of Niantic exit
Time start: **11:30 AM**
Time finish: **12:00 PM**
Observer: **Mohiuddin Imran and Al-Adib Sarker**
Series of photos taken? Y / N **Yes**
Air temp: **35 F**
Pavement temp: **35 F**
Wind speed Leeward: **0 mph**
Wind direction: **CALM**

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Insert numbers for stake here							
	63	59	55	44	41	37	ROW Fence
Insert numbers for stake here	12"	13"	14"				
	62	58	54	45	40	36	
Insert numbers for stake here	7"	6"	7"				
	61	57	53	46	39	35	
Insert numbers for stake here	5"	5"	4"				
	60	56	52	47	38	34	
Insert numbers for stake here	5"	5"	6"				

Edge of West bound I-72

Other notes of importance:

Note: Actual local area weather information should be included with each report.

Figure 105. Table. I-72 MM 127 check field measurements on January 17, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/18/2019
Location Site Number: 6 Check Plot
Location description: I-72 MM 127 West of Niantic exit
Time start: 9:09a
Time finish: 9:13a
Observer: PAH,NA
Series of photos taken? Y / N Y
Air temp: 28
Pavement temp:
Wind speed Leeward:
Wind direction: Calm

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

Insert numbers for stake here							
	55	54	47	46	39	38	ROW Fence
Insert numbers for stake here	11"	12"	12"				
	56	53	48	45	40	37	
Insert numbers for stake here	6"	6"	7"				
	57	52	49	44	41	36	
Insert numbers for stake here	4"	5"	4"				
	58	51	50	43	42	35	
Insert numbers for stake here	4"	4"	6"				

Edge of West bound I-72

Other notes of importance:

Pre-Storm Baseline

Note: Actual local area weather information should be included with each report.

Figure 106. Table. I-72 MM 127 check field measurements on January 18, 2019.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/11/18
Location Site Number: 1
Location description: I-80 LaSalle MM 83.5

Mature Honeysuckle with Prairie Grass

Time start: Base Line
Time finish:
Observer: Darrell Tiesman
Series of photos taken? No
Air temp:
Pavement temp:
Wind speed windward:
Wind speed Leeward:
Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	69	68			49	48		38	27		17		7	6
Insert numbers for stake here	*	*			*	0"		0"	0"		0"		0"	0"
	70	67			50	47		37	28		18		8	5
Insert numbers for stake here	0"	0"			0"	0"		0"	0"		0"		0"	0"
	71	66	59	58	51	46	39	36	29	26	19	16	9	4
Insert numbers for stake here	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"
	72	65	60	57	52	45	40	35	30	25	20	15	10	3
Insert numbers for stake here	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"
	73	64	61	56	53	44	41	34	31	24	21	14	11	2
Insert numbers for stake here	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"
	74	63	62	55	54	43	42	33	32	23	22	13	12	1
Insert numbers for stake here	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"	0"

Edge of roadway

Other notes of importance: Maintenance from this area mowed down all of the prairie grass within this test site. Also some of the stakes were damaged as a result of their mowing.
* = Missing stake. Note: Actual local area weather information should be included with each report.

Figure 107. Table. I-80 MM 83.5 field measurements on January 11, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date: 01/16/18
Location Site Number: 1
Location Description: I-80 LaSalle MM 83.5

Mature Honeysuckle with Prarie Grass

Time Start: 4/18 at 4:30 PM
Time Finish: 6/18 at 3:30 PM
Observer: Darrell Tiesman
Series of photos taken? No
Air temp: - 25 degrees
Pavement temp: - 25 degrees
Wind speed windward: 15 - 25 mph
Wind speed Leeward: 15 - 25 mph
Wind direction: SW and N
Snow Accumulation: 2 Inches
Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	69	68			49	48		38	27		17		7	6
Insert numbers for stake here	*	*			*	12"		10"	10"		8"		8"	8"
	70	67			50	47		37	28		18		8	5
Insert numbers for stake here	8"	10"			10"	12"		10"	10"		8"		8"	8"
	71	66	59	58	51	46	39	36	29	26	19	16	9	4
Insert numbers for stake here	8"	9"	12"	8"	8"	8"	10"	10"	10"	10"	8"	10"	8"	8"
	72	65	60	57	52	45	40	35	30	25	20	15	10	3
Insert numbers for stake here	8"	9"	8"	8"	8"	8"	8"	10"	10"	8"	8"	10"	8"	8"
	73	64	61	56	53	44	41	34	31	24	21	14	11	2
Insert numbers for stake here	8"	10"	8"	8"	8"	8"	8"	10"	10"	8"	8"	10"	8"	8"
	74	63	62	55	54	43	42	33	32	23	22	13	12	1
Insert numbers for stake here	8"	8"	8"	8"	8"	8"	8"	10"	10"	8"	8"	10"	8"	8"

Edge of roadway

Other notes of importance: Maintenance from this area mowed down all of the prairie grass within this test site. Also some of the stakes were damaged as a result of their mowing.

* = Missing stake. ALL MEASUREMENTS ARE IN INCHES. Note: Actual local area weather information should be included with each report.

Figure 108. Table. I-80 MM 83.5 field measurements on January 16, 2018.

Living Snow Fence Field Measurement Spreadsheet

Date: **02/12/2018**

Mature Honeysuckle with Prairie Grass

Location Site Number: 1

Location description: I-80 LaSalle

Time start: 10:01

Time finish: 10:35

Observer: Cornwell

Series of photos taken? Y / N Yes

Air temp: around 6 F

Pavement temp:

Wind speed windward:

Wind speed Leeward: < 3

Wind direction:

Fill in each measurement to the foot and closest inch for each measuring pole

Yellow grids indicate a field stake

	69	68			49	48		38	27		17		7	6
Insert numbers for stake here	n/a	n/a			n/a	n/a		n/a	n/a		n/a		n/a	n/a
	70	67			50	47		37	28		18		8	5
Insert numbers for stake here	cant read	n/a			n/a	n/a		n/a	n/a		n/a		n/a	n/a
	71	66	59	58	51	46	39	36	29	26	19	16	9	4
Insert numbers for stake here	17"	20"	24"	17"	15"	14"	15"	15"	18"	16"	12"	23"	n/a	missing
	72	65	60	57	52	45	40	35	30	25	20	15	10	3
Insert numbers for stake here	17"	16"	15"	17"	15"	14"	14"	11"	15"	15"	11"	23"	n/a	10"
	73	64	61	56	53	44	41	34	31	24	21	14	11	2
Insert numbers for stake here	15"	17"	16"	18"	19"	14"	14"	13"	14"	14"	12"	23"	11"	12"
	74	63	62	55	54	43	42	33	32	23	22	13	12	1
Insert numbers for stake here	14"	12"	13"	13"	13"	12"	12"	12"	12"	13"	13"	20"	15"	15"

Edge of roadway

Other notes of importance: Picket fence is part of fence from column G to L. Prairie grass had unfortunately been mowed.
If prairie grass would have remained it would be hard to read measuring poles but suspect we may have trapped more snow.
It would be good if there was a way to shoot video of blowing snow in and out of our LSF test areas.

Note: Actual local area weather information should be included with each report. I have been using Weather Underground Roanoke, Illinois.

Note: Steps for recording information at each site
1. Set up all safety beacons, flashers, and reflective vests
2. Begin filling out paper spreadsheet copy for site
3. Take all necessary photos. I start by taking a photo from the middle of the right side of the site,
and then from the right to left between each two poles take a series of photos at the same location and height on the pavement shoulder.
4. Collect all measuring pole data following the numerical sequence on the grid.
5. Record all other necessary information on the sheet, including any important notes.

Figure 109. Table. I-80 MM 83.5 field measurements on February 12, 2018.

APPENDIX D: STEPS OF ESTIMATING LSF POROSITY USING DIGITAL PHOTOS

This appendix presents a procedure for estimating the porosity of an LSF using digital images of the fence and the free image analysis software, ImageJ.

(1) Open the free ImageJ software (available at: https://imagej.nih.gov/ij/).

(2) Open the digital image of the living snow fence (The digital photo ideally should have been taken in the direction parallel to the prevailing wind direction. If needed, a light source could be employed to enhance the quality of the photo. If there were multiple rows of the LSF, then a photo should be taken for each row at consistent direction and magnification to enable the overlap of all photos into one single photo, for more accurate estimation of fence porosity).

(3) Image – Type – RGB stack. Convert original images to RGB-stack images.

(4) Image – Adjust – Brightness/Contrast. Make all objectives black.

(5) Image – Adjust – threshold. Adjust threshold of objectives to make them red.

(6) Analyze – Set measurements. Select area and area fraction.

(7) Analyze – Measure. The result is the percentage of the red area in the whole area. (But the output image is a black-white image). Porosity can be calculated by (1 – the percentage).

(8) For the images that are difficult to adjust bright and threshold, they need to be processed using Microsoft PowerPoint before being analyzed in ImageJ. One example is given below.

Comment: Only the suitable areas of the original image were selected and analyzed with ImageJ.
This was to reduce errors in the result that could have been contributed by the irrelevant areas in the original image.

APPENDIX E: LIST OF PLANT SPECIES FOR ILLINOIS LIVING SNOW FENCES

Botanical name	Common Name	Vegetation Type	Mature height*	Mature spread*	Estimate Porosity at 10 years	Plant spacing	Native Illinois/ North America
Cornus sericea	Red Osier Dogwood	Shrub	6-8'	8-10'	45%	6' OC	yes/cultivar
Corylus americana	American Filbert	Shrub	8-16'	8-10'	45%	6' OC	yes
Physpcarpus opulifolius	Common Ninebark	Shrub	6-10'	6-10'	50%	6' OC	yes
Prunus americana	Wild Plum	Shrub	15-25'	15-25'	40%	12' OC	yes
Sambucus canadensis	Common Elderberry	Shrub	8-10'	8-10'	45%	6' OC	Yes
Viburnum lentago	Nannyberry Viburnum	Shrub	15-20'	10-15'	50%	10' OC	yes
Viburnum dentatum	Arrowwood Viburnum	Shrub	6-10'	6-12'	55%	10' OC	yes
Viburnum trilobum	Highbush Cranberry Viburnum	Shrub	8-15'	8-12'	50%	10' OC	yes
Craetegus phaneophrum	Washington Hawthorne	Tree	20-30'	20-25'	45%	10' OC	Yes

Botanical name	USDA Plant Zone	Growing Conditions	Growth Rate	Multi-stem	Salt tolerance	Ease to establish	Readily commericially available	Maintenance	Other Factors: Birds/Pollenators/etc.
Cornus sericea	4 to 9	prefers moist soils but soil tolerant	fast	yes	yes	yes	yes, cultivars	can be mown	Red stems, good for birds
Corylus americana	4 to 7	prefers loamy, well drained soil	moderate/fast	yes	yes	yes	yes	https://www.mortonarb.org/trees-plants/tree-plant-descriptions/american-hazelnut	Suckering, nuts favored by birds/animals https://web.extension.illinois.edu/shrubselector/detail_plant.cfm?PlantID=374 https://www.possibilityplace.com/our-plants/corylus-americana
Physpcarpus opulifolius	2 to 7	tolerant of most soils	moderate	yes	yes	yes	yes, cultivars	Can be rejuvinated by cutting off to ground	Tolerant of dry sites
Prunus americana	3 to 8	soil tolerant	moderate	suckers and can be thicket forming	no	yes	yes	Can be a maintenance problem due to suckering and seeding, hard to get trash out of colony	VERY wildlife friendly
Sambucus canadensis	3 to 9	Prefers acidic soil but generally pretty soil tolerant	moderate-fast	yes, clump forming	yes	Tolerates occasional wetness	yes	Prune to size, may be short lived	Attracts many birds and pollinators
Viburnum lentago	3 to 7	Tolerant of most soils	moderate	yes, thicket forming	moderate	yes	yes	Mow to control suckers	Birds attracted to fruit in fall/winter
Viburnum dentatum	2 to 8	Soil tolerant	moderate to fast	yes, thicket forming	moderate	yes	yes	low	Excellent for many bird species
Viburnum trilobum	2 to 7	Soil tolerant	moderate	yes, thicket forming	moderate	yes	yes	low	Berries attract birds and is host to many butterflies
Craetegus phaneophrum	3 to 8	fairly soil tolerant	Moderate	no	Intolerant of salt spray	yes	yes	Susceptible to many leaf and foliar diseases	Thorny, excellent for game birds, song birds and migratory birds

References used in compiling this Living Snow Fence (LSF) plant database for Illinois highways

Morton Arbortetum, Lisle, Illinois. Note: This site was used as a primary source
"Roadside Use of Native Plants" FHWA, Editted by Bonnie Harper Lowe and Maggie Wilson, August 2000, Island Press
"Trees, Shrubs and Vines; A Pictoral Guide to the Ornamental plants of the Northern United States, Exclusive of Conifers", Arthur T. Viertel, 1970, Syracuse University Press
mn.us/roadsides/plantselector/ 2020 Minnesota Department of Transportation
University of Illinois Extension, Selecting Native Plants, Champaign, Illinois extension.illinois.edu./cook/selecting native plants
plantfindersearch.aspx
"Manual of Woody Landscape Plants", Michael A.Dirr, Department of Horticulture, University of Georgia, 4th Addition, Stipes Publishing
"Taylors Guide to Shrubs", 1987, Houghton Mifflin
"Forest Trees of Illinois", Robert H.Mohlenbrock, Department of Botany, Southern Illinois University, Department of Conservation
Illinois Natural History Survey, inhs.illinois.edu Champaign, Illinois
Department of Forestry, University of Illinois
Lady Bird Wildflower Center, wildflower.org
Missouri Botanical Garden Plant Finder, missouribotanicalgarden.org/plantfinder
Minnesota Wildflowers, minnesotawildflowers.info New Brighton, MN
Bailey Nursery, baileynurseries.com Onarga, Illinois
Possibility Place Nursery, Kelsay Shaw, Monee, Illinois
Illinois Invasive Species invasives.org/illinois/
http://www.salinitymanagement.org/Salinity%20Management%20Guide/index.html
http://woodyplants.cals.cornell.edu/collections/woody-shrubs-storm-water.pdf
https://www.ecolandscaping.org/02/designing-ecological-landscapes/native-plants/native-shrubs-for-the-increasingly-challenging-landscape-environment/

Notes:

* It is assumed that harsh growing conditions common to highway ROW's will influence growth, both height and width. Furthermore, contaminants such as road salt, herbicide drift, high winds compacted soils, poorly drained soils, auto/truck air pollution, utilities, and many other factors can disfigure and stunt plant growth. Mature height and width assume good growing conditions.

Cuttings could be produced at the Mason State Tree Nursery for other larger scale nurseries to grow out.

This is the approved plant list from the Roadside Management Team at IDOT.

For a more expanded list of potential plant species for LSF for Illinois highways, an expanded list was provided to IDOT but many of the species have missing information and would require additional research in the future.

APPENDIX F: POTENTIAL ILLINOIS NURSERIES FOR LSF PLANTS

This appendix provides links to plant nursery sources in Illinois as follows. This is provided for your convenience and is not intended to be exclusive or comprehensive.

- http://www2.illinois.gov/dnr/conservation/Forestry/Pages/Tree-Nurseries.aspx
- http://illinoisprairie.wildones.org/resources/nurseries/
- http://plantnative.org/nd.idloks.htm#il
- http://ecologyactioncenter.org/wp-content/uploads/2018/03/Native-Nurseries.pdf
- http://castle.eiu.edu/n_plants/lists/nurseries_il.html
- http://nurserypeople.com/companies/locations/illinois
- http://agr.state.il.us/sharepoint/licenselist.php?facc=NURSERMEN
- http://nurserytrees.com/States/state%20Illinois.htm

APPENDIX G: PARTNERSHIP CONSIDERATIONS

It has been well documented that living snow fences (LSFs) can save lives, reduce accidents, improve traffic mobility, reduce winter operational costs, reduce salt use, and create more opportunities for employee productivity. While there are countless needs for infrastructure improvements across the United States, it is apparent that funding sources are challenged. Highway agencies are also too busy managing existing highway infrastructure needs and may find it difficult to take on new proactive challenges such as implementation of LSFs.

In this context, partnership building through public and private engagement is part of the solution, both before, during, and after LSF installation. One success story is the Community Roadside Landscape Partnership Program implemented by the Minnesota Department of Transportation (MnDOT). According to MnDOT (https://www.dot.state.mn.us/roadsides/partners/background.html), "MnDOT has fostered over 350 projects and worth over 7 million dollars of roadside landscaping improvements in communities (through partnerships,) while spending less than one third of that amount in State Highway Funds. Additionally, MnDOT benefits from an annual cost savings/avoidance of nearly $1.75 million dollars for ongoing work necessary to maintain the landscape plantings."

As road agency funds remain stagnant or decline, it will be imperative to incorporate nontraditional partners in problem-solving to meet future needs of the transportation industry. Harnessing the power of multiple interests can help find new solutions to achieving multidimensional problems such as snow drifting on highways. Snow drifting on highways create hazardous driving conditions. Plowing and salting can be effective, but there are limits as to how much resources an agency can reasonably invest to mitigating snow drifting and even then there is no guarantee that those reactive efforts will assure complete public safety.

Implementation of LSFs on needed highway areas across the state of Illinois will require significant financial and labor investments. There are likely many organizations that could be engaged to support the implementation of LSFs, given that LSFs can serve multiple functions (snowdrift mitigation, landscaping and erosion control, carbon sequestration, etc.). The taxpayers of Illinois and the insurance companies paying losses due to hazardous road conditions would be logical first candidates. Insurance companies pay claims for accidents and then pass the costs back to the end user in the form of higher insurance rates. From a financial standpoint, Illinois citizens would support the concept of LSFs, but in order to achieve this, they will need to fully understand the value.

Nontraditional partnering has demonstrated success through special interest groups such as environmentalists, hunting groups, bird enthusiasts, alternative agriculture groups, soil protection entities, water and air quality entities, and many others. These groups are eager to support novel ideas and actions that further their goals and agendas while benefiting society. Many private entities have seen the value of positive public relations for their businesses through these kinds of community enhancement efforts. Continued volunteer success can be predicated on having a good experience, developing pride in their work, and receiving the proper and vigorous recognition for their efforts.

APPENDIX H: DESIGN SPREADSHEETS

The following spreadsheets are provided to assist in designing LSFs on flat terrain and embankments. Example values are included to demonstrate the calculations.

Living Snow Fence Design Spreadsheet - Flat Terrain

Description:

This spreadsheet is intended to assist in the design of living snow fences on flat terrain or terrain with a longitudinal slope less than 15° (upward or downward). This spreadsheet can also be used for fences on an embankment when the longitudinal direction is oriented along the embankment slope.

(shaded cell)	Fill in requested data

Step 1. Available setback (*L*)

The available setback is measured perpendicular to the road.

L =	150	ft

Step 2. Wind characteristics

Design wind speed, *U* =	30	mph
Prevailing wind direction =	S	(General description of direction)

Note: As a convention, direction is reported as the direction **from** which the winds are blowing.

Angle of attack relative to the road, α_r =	90	degrees

Note: If α_r < 55°, LSF will be less effective. Alternative measures should be considered.

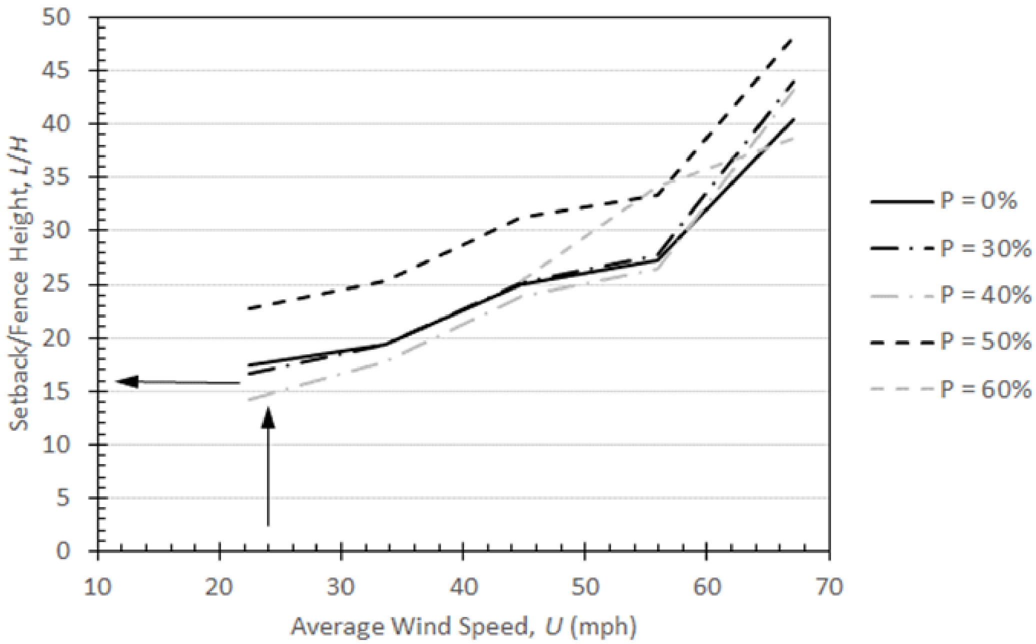
Step 3. Fence porosity (*P*)

Provide a estimate of fence porosity. Fence performance is generally best for Porosty values close to 50%.

P =	50	%

Step 4. Calculate initial fence height (*H*)

Use the design wind speed and figure below to determine the ratio of setback to fence height, *L* /*H* .



The available setback should be reduced for design to provide a factor of safety.

Reduction of available setback =	1.00	(≤ 1.0)	
Setback for design, L =	150	ft	
L/H =	25	ft/ft	(Read value from figure)
H =	6	ft	

Step 5. Select and confirm species for fence

To determine the species for the fence, see the PLANT LIST sheet and select a species with the following characteristics:

Mature height =	6	ft
Porosity =	50	%

Species for fence = *Illinois Rose*

If a species that meets these requirements cannot be found, return to Step 3 with a different value of porosity and repeat Steps 4 and 5 until an appropriate species is identified.

Living Snow Fence Design Spreadsheet - Embankments

Description:

This spreadsheet is intended to assist in the design of living snow fences on embankments with a slope up to 1.5:1 (H:V) or 34°.

(shaded)	Fill in requested data

Embankment geometry

Height, H_e =	15	ft
Slope =	1.5	:1 (H:V)
Horizontal length of slope =	22.5	ft
Length along slope =	27.0	ft
Slope angle =	33.7	degrees

Step 1. Select the species for the fence

In this step, initial species are selected for the fence at the base and fence(s) on the slope.

20% of the embnkment height, $0.2H_e$ =	3.0	ft

(a) Fence at the base of the embankment

Select a species from the PLANT LIST sheet with a mature height of at least $0.2H_e$ and a porosity close to 50%.

Species for fence at base =		
Height, H_b =	3.0	ft

Porosity, P = 50 %

(b) Fences on the embankment

Select a species from the PLANT LIST sheet with a mature height at or below $0.2H_e$ and a porosity close to 50%.

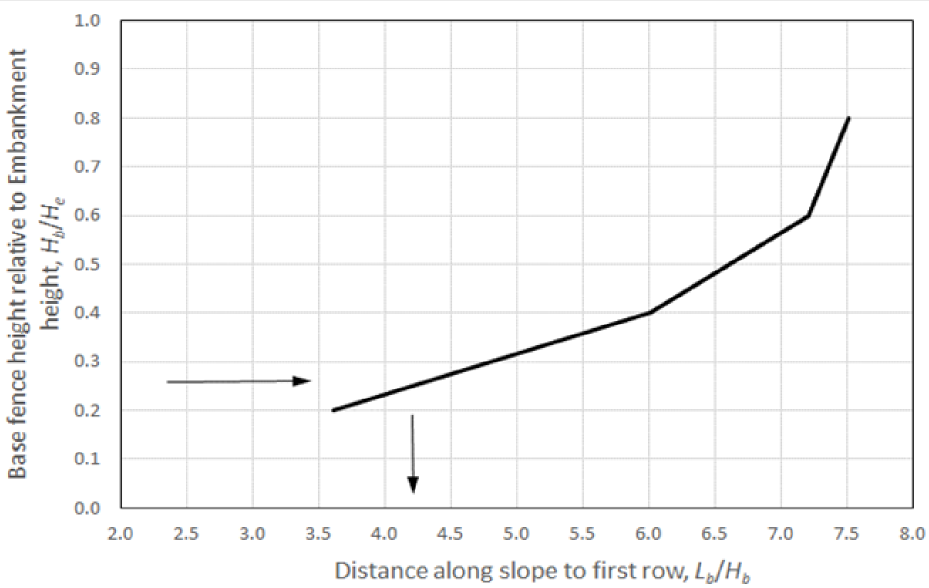
Species for fence on slope =

Height, H_s = 3.0 ft

Porosity, P = 50 %

Step 2. Determine the location for the first row on the embankment

Use the ratio of the fence height at the base to the embankment height.



H_b/H_e =	0.20	ft	
L_b/H_b =	3.6	ft/ft	(Read value from figure)
L_b =	10.8	ft	(measured parallel to slope)

Step 3. Determine the spacing between rows on the embankment slope

The spacing between rows on the embankment should be about 2 times the fence height.

$L_s \approx 2H_s \approx$ 6.0 ft

Step 4. Determine the distance between the last row and the top of the embankment

The spacing between the last row and top of the embankment should larger than 2.5 times the fence height.

$L_n \geq 2.5H_s \geq$ 7.5 ft

Step 5. Finalize the fence configuration

Fence(s) on slope of embankment

Number of rows on slope, n = 2

Distance from base to first row = 10.8 ft

Fence at base of embankment

A single row is placed near the base of the embankment

See Step 1(a) for details on this fence