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Innovation in Transportation

Snow Barrier Effectiveness

Prepared by:
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7500 Pan American Freeway NE
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Final Report
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Although snow fences have been successful in reducing snow drifts and consequently the risks to motorists, a New Mexico Department of Transportation (NMDOT) maintenance crew reported that the capacity of these structures has been exceeded at several locations. As a result, snow has accumulated on the roadway at these sites, requiring repeated clearing and significantly increasing plowing costs. Therefore, the objective of this research is to first survey the literature to determine best practices and current state-of-the-practice, to determine factors affecting snow fences performance and to present NMDOT personnel with a practical guide in the design and placement of snow fences. Effectiveness of recommended design methodology is examined by designing and constructing two structures at critical test sites. It is important to note that snow fences are designed for prevailing wind direction and anticipated snow accumulation and as such, they are expected to be effective most of the time, not all of the time. In the instances where wind direction and/or snow accumulation vary from the norm, they may not only be ineffective in trapping snow, but they may also cause the formation of drifts in unexpected directions. Because snow fences should reduce drift formation on the roadways the majority of the time and such occurrences are expected to be rare, their adoption is recommended.

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SNOW BARRIER EFFECTIVENESS

Final Report

by

Dr. Claudia Mara Dias Wilson
Associate Professor
Civil and Environmental Engineering Department
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Socorro, NM 87801

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PREFACE

This report summarizes the Snow Barrier Effectiveness Research Project conducted by the New Mexico Institute of Mining and Technology (New Mexico Tech, NMT) for the New Mexico Department of Transportation (NMDOT) in cooperation with the U.S. Department of Transportation Federal Highway Administration. The motivation for this project came from the observation that at several locations throughout New Mexico, the 4ft (1.22m) vertical slat snow fences commonly used to reduce snow drifts on roadways were quickly reaching their capacity. As a result, snow blown by the wind was continuously accumulating on the road throughout the winter months, requiring constant plowing and increasing risks to motorists.

This project started with a comprehensive literature review to determine best practices, different types of fences available, existing design methodologies, and factors affecting snow barrier effectiveness. Two test sites were selected and snow fences were designed and constructed for evaluation. Although the two winters following the construction of the snow fences did not bring a significant amount of precipitation to the test sites, important information on the performance of the constructed structures were obtained and are reported herein. In addition to this report, a field guide was developed to assist NMDOT personnel in the design and placement of snow fences.

NOTICE

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DISCLAIMER

This report presents the results of research conducted by the authors and does not necessarily reflect the views of the New Mexico Department of Transportation. This report does not constitute a standard or specification.
ABSTRACT

Although snow fences have been successful in reducing snow drifts and consequently the risks to motorists, New Mexico Department of Transportation (NMDOT) maintenance crew reported that the capacity of these structures has been exceeded at several locations. As a result, snow has accumulated on the roadway at these sites, requiring repeated clearing and significantly increasing plowing costs. Therefore, the objective of this research is to first survey the literature to determine best practices and current state-of-the-practice, to determine factors affecting snow fences performance and to present NMDOT personnel with a practical guide in the design and placement of snow fences. Effectiveness of recommended design methodology is examined by designing and constructing two structures at critical test sites. It is important to note that snow fences are designed for prevailing wind direction and anticipated snow accumulation and as such, they are expected to be effective most of the time, not all of the time. In the instances where wind direction and/or snow accumulation vary from the norm, they may not only be ineffective in trapping snow, but they may also cause the formation of drifts in unexpected directions. Because snow fences should reduce drift formation on the roadways the majority of the time and such occurrences are expected to be rare, their adoption is recommended.
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This research would not have been possible without the assistance and proficiency of Keli Daniell, project manager for this contract and Deirdre Billingsley, contract administrator. The author is very thankful for the help and support received from members of the Technical Panel who carefully reviewed all reports, offered invaluable suggestions, and answered numerous questions: Steve Briggs, Consuelo Chavez, Paul Gray, John McElroy, Elias Sanchez, Chris Vigil, and especially Mark Anaya, Scott Kirksey, and Mary Pacheco.

Thanks are also extended to Mrs. Kathy Ahlenius from the Wyoming Department of Transportation (WyDOT) Winter Research Services who gracefully answered our numerous questions, introduced us to the WyDOT Winter Research Program, provided us with various documents essential to the completion of this project, kindly conducted our visit to the WyDOT and several field sites.

Finally, the author would like to acknowledge the involvement of Dr. Andrew Budek-Schmeisser and Mrs. Barbara Budek-Schmeisser in nearly all phases of this project. They were essential members of the research team and this project could not have been completed without their valuable and extensive contribution. Portions of this document report on work conducted by these individuals and are noted as such.
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INTRODUCTION

The New Mexico Department of Transportation (NMDOT) has been using 4ft (1.2m) vertical slat snow fences to help reduce snow drifts on roadways. Although effective in most places, NMDOT maintenance crew reported that these structures were reaching their capacity and losing their effectiveness at several locations. In some instances, prolonged low temperatures prevented the snow from melting throughout the winter, resulting in excessive snow accumulation by the fence. Because these locations also experienced high volumes of snowfall early in the winter, the fences would often reached their capacity early in the season and snow blown by the wind would continuously accumulate on the road throughout the winter months, requiring constant plowing. In other locations, the snow was observed to melt a reasonably short period after the storm, making problems related to snow accumulation on the roadways temporary, but just as worrisome. At these locations, winds sustained for long periods of time after snow storms were responsible for the large volume of snow that accumulated by the fences and often buried the structures, rendering them ineffective. Consequently, the objective of this research project is to provide the NMDOT with recommendations for appropriate technology to mitigate problems associated with accumulation of snow along the Department’s right-of-way.

This project was divided into nine tasks: (1) survey of the literature, (2) evaluation of two problematic sites determined by members of the Technical Panel, (3) research legal precedent for the placement of safety structures such as snow fences on private land, (4) determination of critical site parameters affecting the effectiveness of the snow fences, (5) determination of the effects of level of service and cost/benefit analysis, (6) development of a methodology for the selection of effective snow barriers, (7) construction of two snow barriers for evaluation, (8) evaluation of the barriers’ performance, and (9) development of an implementation plan for the methodology developed. Details and results for each of these tasks are presented in this Final Report.
LITERATURE REVIEW

Several practicing engineers and researchers have considered the use of snow fences to reduce the velocity of the wind on the leeward side of the fence, causing the precipitation of the snow and the formation of a drift close to the fence. If placed at an adequate distance from the sides of the roads, these fences can be used to protect them from snow accumulation, helping improve road safety and reducing the need or at least the frequency of plowing (Figure 1). Hurlbut (1), for example, claims that snow removal costs have been reduced by up to 50% with the use of properly designed snow fences. In addition, this same document states that they were found to help improve visibility and reduce automobile accidents by as much as 70%. However, if designed or placed incorrectly, they may become buried by the snow and drifts larger than those obtained without the presence of the fences may result on the roads (2). Reduction in accidents has also been observed by other researchers, but at a more conservative rate. Keith Rounds, a public information officer and secretary to the Wyoming Highway Commission, claimed that the use of snow fences reduced accidents occurring during snow storms and ground blizzards by 22%, accidents occurring during ground blizzards alone by 38%, and accidents occurring due to wind only by 40%. In addition, the number of days of road closures was reduced by 44% (3). Snow fences were also found to benefit watersheds. In fact, the retention of snow by snow fences has helped replenish holding ponds used for watering cattle and agriculture in semi-arid areas (3).

FIGURE 1 Effectiveness of Snow Fences – Dry Road Where Fences Are Present
How Snow Fences Work

Tabler (4 cited in 2) describes the mechanism of snow deposition as follows: when the wind induced shear stress exceeds the shear strength of the snow on the ground, snow particles are eroded and transported. Deposition of these particles will occur when the wind induced shear stress becomes too low for transport. Because the wind induced shear stress is proportional to the velocity gradient, the proper placement of snow fences can cause a change in the wind profile and create favorable conditions for snow deposition. Most of the snow is transported close to the ground, with 95% of the total blowing snow occurring within 4ft (1.2m) of the surface for 26mph (41.8km/h) winds. However, for stronger winds, this value is reduced, for example, for winds of 50mph (80.5km/h), only 75% of the blowing snow occurs within 4ft (1.2m) of the ground. It is also noted that the average maximum fetch distance used in calculations is 10,000ft (3,048m), since it is believed that beyond this value most snow particles will have ablated.

Different Types of Snow Fences Available

Different configurations have been proposed over the years. The Canadian fence (Figure 2), ranging from 4 to 6ft (1.2 to 1.8m) tall and composed of vertical slats 2 inches (5.1cm) wide by 3/8-inch (1cm) thick held together by twisted wires was described in Pugh and Prince (5), as mentioned in Wangstrom (2). These fences can still be found in different areas in the United States, but their use decreased significantly after it was shown that their snow-holding capability was limited and that they commonly became buried after severe snow events, losing their usefulness (3). The Swedish fence (Figure 3) is described as a 6.5ft (2m) structure composed of nine horizontal boards, 6 inches (15.2cm) wide, with a 2.5in (6.4cm) gap between boards (4 cited in 2). Similar fences have been used in Wyoming. However, to increase their storage capacity, these fences have ranged from 8 to 12ft (2.4 to 3.7m) in height (Figure 4). A modified version of these fences, the Wyoming barrier is 8 to 14ft (2.4 to 4.3m) high, and inclined 10 to 15° leeward (Figure 5). It exhibits a gap of 12 to 18in (30.5 to 45.7cm) at the bottom, and although it still uses 6in (15.2cm) wide horizontal boards, they are now spaced 6in (15.2cm) apart (4 cited in 2).

FIGURE 2 Canadian Fence or 4ft (1.2m) Vertical Lath Fence – Eagle Nest, NM
FIGURE 3 Swedish Fence

FIGURE 4 Vertical Wood Fences – Wyoming
Lightweight fences made of high density polyethylene (HDPE) bands woven into a mesh and supported by lightweight thin-walled Pozitube pipe frames were proposed in Wyoming, in 1979, and described in an article published in the Better Roads journal (3). These fences were fabricated by Foresight Industries of Cheyenne, using HDPE 3406 interwoven slats developed by Phillips Discopipe, which are resistant to temperatures as high as 275° and as low as negative 180° F (82°C) before becoming brittle. Slats used were 6in wide and spaced such that 6in (15.2cm) voids were provided between each of them. Pozitube thin-walled pipes were produced by Southwestern Pipe. A socket driven into the earth is used to hold the fence and help it withstand winds of up to 100mph (161km/h). The main advantages of these fences are their portability and versatility, allowing them to be easily removed from their anchors once their capacity is reached and moved to the top of the drift to resume their function. In these cases, concrete horseshoes are used over the legs of the fence to hold them in place over the existing drifts. These fences can be disengaged and relocated by one person and can continue to trap snow at the same location throughout the entire winter.

Fabric snow fences (Figure 6) have also been considered in Alaska. They were 12 to 16ft (3.7 to 4.9m) tall, presented a 40 to 60% porosity, and were built with Tensar™ or Signode Sno-strap™ fabric (1, 2). Other fences built with synthetic material were made by Tenax in Italy and DuPont in Canada. These fences were installed with a bottom gap and their leeward drift was measured as 35 times the height of the fence, that is, three times that of wood-slat fences without bottom gaps. Advantages of the synthetic fences include lightness and compactness, but they also required an assurance of high tensile strength for withstanding wind forces and effectively collecting snow (1). These have been used as temporary structures in Iowa due to their light weight and ease of installation and storage (6).
Living snow fences are also capable of effectively protecting roads by trapping blowing and drifting snow. The Wyoming State Forestry Division (8) website presents the advantages and disadvantages of this snow control alternative (Figure 7). Among their advantages are: (1) longer-lasting than wooden structures, lasting in average 50 to 75 years versus 20 to 25 years for the wooden structures, (2) aesthetically pleasing, (3) provide wildlife habitat, (4) requires little to no maintenance once established, (5) low installation and maintenance costs, estimated at approximately one seventh that of the 12ft (3.7m) wooden fences over the life of each alternative, (6) reduces snow removal costs, (7) carbon dioxide sequestration. Their disadvantages are: (1) they require more space than wooden fences, (2) when recently planted, these fences require protection from grazing, (3) they require time for maturing before they are ready to trap snow effectively, this time is dependent on site conditions, but varies from 5 to 10 years, (4) they may not be a viable option in regions with shallow soils or soils with a pH inadequate for planting. The United States Department of Agriculture (USDA) Natural Resources Conservation Center (9) states that the efficiency of a mature living snow fence is much higher than that a slated fence, and that these systems are capable of capturing 12 times more snow than their structural counterpart. Key design elements specified by the USDA Natural Resources Conservation Center (9) include fence orientation, height, density, and length. Their recommendations state that all living snow fences should be planted at right angles to the prevailing winds, that vegetation with 50% density will capture and store the greatest amount of snow, and that conifers are the ideal species for snow fences because of their height and year-round foliage. Other commonly recommended species are as follows: in the evergreen category: Eastern redcedar, Austrian pine, Blue Spruce, Rocky Mountain juniper, Utah juniper, Scotch
pine, and Ponderosa pine. In the low broadleaf category: Siberian crabapple, Mancharian crabapple, and Russian olive, and in the shrubs category: Amur honeysuckle, Blueleaf honeysuckle, chokecherry, golden current, Peking cotoneaster, Western sandcherry, American plum, common lilac, Silver buffaloberry, Fourwing saltbush, Siberian peashrub (caragana), Skunkbush sumac, and Sagebrush.

FIGURE 7 Living Snow Fence – Wyoming

Living fences started being used in 1905, along railways in North Dakota. In the spring of 1927, Wyoming started planting trees along its roadways, but the drought of 1930 proved too hard on the vegetation. It was not until 1983 that the Wyoming State Forestry Division and the Wyoming Department of Transportation attempted to use living snow fence once again. Three locations were selected in Laramie County and this time, drip irrigation systems were used to assure sufficient moisture would be provided to the plants. In 1998, the Wyoming Association of Conservation Districts joined the other two organizations in the launching of a statewide living snow fence program which today protects 55,529 feet (16,925m) of public roadway.

The Minnesota Department of Transportation (Mn/DOT) also invested in the development of a snow fence program for controlling blowing and drifting snow (10). The structural snow fences used by the Mn/DOT are made of polyethylene rails with inserted bonded cables and wood or steel posts, as shown in Figure 8. These structures are recommended for sites not conducive for tree and shrub planting, such as areas where there is concern regarding the use of herbicide, or regions where the soil pH is above 8.0 or where the soil is too compacted, too wet, too dry or too rocky to permit the proper development of roots. Because of the labor involved in installing and removing such structures, they are left permanently on the site. For this reason Mn/DOT usually acquires an easement or enters into an agreement with the landowner. Ditches are also used by the Department to catch the snow before it is blown across the roads, as presented in Figure 9. Minimum requirements for effective ditches include a minimum distance of 46ft (14m) from the
edge of the pavement to the toe of the backslope, a depth of at least 4ft (1.2m), and a distance from the edge of the pavement to the top of the backslope determined according to the following equation:

\[ W_{\text{Top}} = 95 + (\sin \alpha) 5.8 \, H \]  

(1)

where \( W_{\text{Top}} \) is the distance from the point of intersection of the road to the top of the backslope, \( \alpha \) is the attack angle of the prevailing winds, and \( H \) is the height of the cut. The snow control method preferred by Mn/DOT seems to be the use of living snow fences which provides landowners enrolled in the CP 17A-Living Snow Fence Practice within the Continuous Conservation Reserve Program an annual compensation for up to 15 years for the acreage enrolled in the program, the inconvenience of farming around the living fence, the work involved in growing and maintaining the snow fence. Regular maintenance activities are a responsibility of the landowner and include watering, mowing, weed control, pruning, re-anchoring landscape fabric, and scouting the plants for insects, diseases, environmental, mechanical or chemical damages. However, support is provided by the Mn/DOT in cases where adverse plant health changes are observed. Other organizations participating in this program are the United States Department of Agriculture (USDA) Farm Service Agency and the USDA Natural Resources Conservation. In addition to the benefits listed previously, living snow fences serve as visual clues and/or landmarks to help drivers find their way, they provide wildlife habitat, control soil erosion, sequester carbon to reduce atmospheric carbon dioxide, and decrease home heating costs when placed near the farmhouse. Finally, every year Mn/DOT purchases standing corn rows from farm areas adjacent to highways that have experienced problems with blowing and drifting snow (Figure 10). To serve as a snow fence, corn rows need to be parallel to the road and a typical corn row snow fence is set 120 to 240ft (36.6 to 73.2m) from the right-of-way, is one-quarter-mile (402m) long and 16 rows wide (1.2 acres).

FIGURE 8 Snow Fence Protecting US Highway 14 near Cobden, Minnesota (10)
FIGURE 9 Ditch Protecting Road in Minnesota from Blowing Snow (10)

FIGURE 10 Standing Corn Row Snow Fence – Minnesota (10)
Another living fence snow fence program was created by the Iowa Department of Transportation (11, 12). This program is part of the Iowa’s Cooperative Snow Fence Program which recommends a variety of solutions for the problem of drifting snow. Among them are: permanent and temporary structural fences, standing corn rows, living trees, shrubs, or native grasses, or Conservation Reserve Program (CRP) living snow fences, as presented in Table 1. In the Conservation Reserve Program, landowners are able to receive annual payments for up to 15 years if they follow the planting recommendation of the Iowa DOT: two rows of trees or a combination of trees and shrubs followed by a buffer section of 75 to 100ft (23 to 30.5m) of native grasses, as shown in Figure 11.

**TABLE 1 Snow Control Methods Proposed by the Iowa’s Cooperative Snow Fence Program (12)**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Advantages</th>
<th>Agreement length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural, permanent</td>
<td>6 to 8ft (1.8 to2.44m) tall fence consisting of 2 wooden posts, lightweight plastic fence and 2”x 4” (5.1 x 10.2cm) supports.</td>
<td>Very low maintenance. Takes up as little as one-foot width of land.</td>
<td>10 year minimum</td>
</tr>
<tr>
<td>Structural, temporary</td>
<td>4ft (1.2m) tall portable plastic fence or wooden fence.</td>
<td>Installed after harvest and removed before planting.</td>
<td>Fall to Spring</td>
</tr>
<tr>
<td>Standing corn</td>
<td>One section of 8 to 16 rows of corn.</td>
<td>Can reduce soil erosion. Public service organizations benefit from picking by hand. Wildlife habitat.</td>
<td>Fall to Spring</td>
</tr>
<tr>
<td>Living trees, shrubs, or native grasses</td>
<td>Two or more rows of trees or shrubs, or a combination of both.</td>
<td>Wildlife habitat. Reduces soil erosion. Hunting ground.</td>
<td>10 year minimum</td>
</tr>
<tr>
<td>CRP living snowfence</td>
<td>Two or more rows of trees or shrubs, or a combination of both with 75-100ft (23-30m) native grass buffer.</td>
<td>Wildlife habitat. Reduces soil erosion. Hunting ground.</td>
<td>10-15 years per CRP program guidelines</td>
</tr>
</tbody>
</table>

**FIGURE 11 Iowa’s Conservation Reserve Program – Living Snow Fences (12)**
Factors Affecting Snow Fence Capacity

As mentioned previously, snow fences function by reducing the velocity of the wind on the leeward side of the fence, hence reducing its carrying capacity and causing the precipitation of the snow and the formation of a drift close to the fence. Figure 12 illustrates this process where Y denotes the height of the drift, H the height of the fence above the ground cover and X the horizontal distance from the fence. If placed at an adequate distance from the sides of the roads, these fences can be used to protect them from snow accumulation, helping improve road safety and reducing the need or at least the frequency of plowing. However, if designed or placed incorrectly, they may become buried by the snow and drifts larger than those obtained without the presence of the fences may result on the roads (2).

Research has shown that the main factors affecting the efficiency of snow fences are (in no particular order): (1) height, (2) length, (3) porosity, (4) gap at the bottom of the fence, and (5) placement. The effects of these variables on the capacity of the snow fences are presented below.

![Figure 12 Progressive Formation of Snowdrift by a 12.4ft (3.8m) 50% Porous Horizontal-Board Fence (13)](image)

**Height**

The height of the fence is one of the most influential variables in design because of its effect on the fence’s storage capacity. According to Tabler (13), for fences with 50% porosity, the maximum height of the downwind drift will be 1.0 to 1.2 times the height of the fence. As shown in Figure 12, this maximum height is achieved during stage 3 of the snowdrift formation sequence. After the maximum height is achieved, the drift starts to stretch downwind as its relatively sharp slope is filled. At this point, the trapping efficiency of the fence declines and snow deposition from stages 4 to 7 is slow (13).

However, Tabler (13) observed that the airflow over fences shorter than 4.5ft (1.5m) tall, was different than that of the taller structures studied. In fact, he often observed that these short
fences would be partially buried before the drift behind them would cease to grow. As shown in Figure 13, this reduces the fence’s height above the snow cover (effective height), and renders it less effective.

The height of snow fences not only affect the height achieved by the drift, but it is also important when one considers the fact that snow transported by the wind usually travels close to the surface. In fact, for a wind speed of 26mph (41.8km/h), 95% of the snow is transported within the first 4ft (1.2m) above the ground and 99% within 12ft (3.66m), while for 50mph (80.5km/h) winds, 77% of the snow is being transported within the first 4ft (1.2m) and 95% within the first 12ft (3.7m) (1). Therefore, where high winds are expected, fences of approximately 12ft (3.7m) would be desirable. Yet, it is important to note that the relationship between snow transport and wind speed is not linear (13).

Finally, because taller fences require less space than multiple rows of smaller fences (14) and because one row of 8ft (2.4m) fence can trap as much snow as five rows of 4ft (1.2m) fence (15, 11,12), when possible, a single row of tall fences should be used.

![Diagram](image)

**FIGURE 13** Effect of Partial Burial of a Snow Fence on Drift Formation (16)

*Length*

The length of the fence is also an important design factor because rounding of the drifts occurs near the ends of these structures (Figure 14), reducing their storage capacity (1, 2, 13, 15). Hurlbut (1) recommends that fences be constructed with lengths of at least 30 times the height of the fence, and that they be extended at least a distance of 13 times the height of the fence beyond
the area to be protected to allow for wind direction variations. To compensate for the observed diminished storage capacity near the ends of a barrier compared to more centralized regions of the fence, the USDA Natural Resources Conservation Service (9) requires snow fences to be extended at least 100ft (30.5m) beyond the area to be protected, Tabler (13) recommends an extension of 12 times the height of the fence, and the Iowa Department of Transportation (11,12) recommends an extension of the ends approximately 30 degrees beyond the desired protection limits to allow for wind variability (Figure 15).

FIGURE 14 End Effect (17 cited in 16)

FIGURE 15 Iowa Department of Transportation (11, 12) Recommends that Snow Fences’ Ends Be Extended Approximately 30° beyond the Desired Protection Limits

Porosity

Performance of a snow fence is also affected by the porosity of the fence or the “solidity ratio” which Williams (18) defines as the area actually covered by fencing material divided by the total frontal area of the fence, and gives an idea of the fence’s permeability. A “porosity ratio” has also been used to measure the permeability of the fence, and has been defined by Hurlbut (1) as the ratio of open area to total fence area.
The effect of the fence’s porosity has been extensively analyzed because it affects the size of the vortices that create the turbulence behind the fence (1). The large vortex produced by solid fences was found to reduce their trapping and storage capacities compared to porous fences which generated small eddies. In the case of solid fences, the snow was initially deposited very close to the fence, eventually burying it and preventing the collection of additional drifting snow (1, 18). The collecting capacity of solid snow fences was found to be approximately one third that of fences with 50% porosity and a bottom gap (1, 2, 3). Although researchers such as Williams (18) and Shelquist (6) have claimed that fences with a porosity ratio of 0.5 would collect the largest volume of drifting snow, Hurlbut (1) believes that the size of the apertures should also be considered. If these openings are too small, they will restrict air movement through the fence which will behave as a solid fence, even if its porosity ratio is 0.5. It is also important to note that the conclusion that fences with a porosity ratio of 0.5 collect the largest amount of snow is not shared by all researchers. Brugnot (19), for example, compared 7 different types of snow fences and observed that the effectiveness of the snow barriers increased with increasing porosity and that the barrier with a porosity ratio of 0.7 (the only one with a porosity ratio larger than 0.5) was the one that accumulated the largest amount of snow. This researcher observed that the change in porosity strongly affected the shape of the drift: increasing porosity resulted in an elongation of the drift, a shortening of its height, and an increase of the amount of snow stocked. These findings agree with research conducted by Tabler (13) presented in Figure 16.

![Figure 16 Effect of Fence Porosity on Shape of Snowdrifts (13)](image)

**Bottom Gap**

Another factor that was found to considerably affect the performance of a snow fence is the gap beneath the structure. Because the bottom gap forces the wind to speed up under the fence, it prevents snow deposition close to the toe of the fence, hence preventing the fence from being buried in snow (1, 2, 19). This problem seemed more critical in barriers with horizontal slats than in those that used vertical slats (19).
The gap beneath snow fences impacted by wind at a 90° angle was found to control the position of the drift. For instance, if a very small gap or if no gap is present beneath the fence, the drift will form very close to the fence, and often cover the bottom portion of the fence. On the other hand, a larger gap will cause the drift to form further away from the fence. Hurlbut (1) and Tabler (4 cited in 2) recommend a gap of 0.10 (for fences with vertical slats) and 0.15 (for fences with horizontal slats) times the height of the fence. Larger gaps should be used when terrain is sloping downward in the direction of the wind (1).

Finally, Tabler (13) found that the bottom gap was more effective in fences with horizontal slats than those with vertical slats. This is because snow tended to deposit closer to the toe of fences with vertical slats, as shown in Figure 17. In addition, fences with horizontal slats have the advantage of having the space between rails function as a bottom gap in the event that their toe becomes buried.

![Efficiency of Bottom Gap on Fences with Horizontal Slats vs. Fences with Vertical Slats and No Gap](image)

**FIGURE 17 Efficiency of Bottom Gap on Fences with Horizontal Slats vs. Fences with Vertical Slats and No Gap (13)**

*Fence Placement*

The placement of the fence will also strongly affect its performance. To effectively protect a road or any other area of interest, the length of the drifts relative to the height of the fence should first be estimated and the fence should evidently be placed no closer to the protected area than this estimated distance. In some instances, this distance will be quite large and a fetch area can
be created between the fence and the road. In these cases a row of smaller fences may be placed between the larger fence and the area to be protected. When using multiple rows of fences, care should be taken not to place them too close together for it may cause the burial of adjacent rows.

Recommendations on the distance from the road to the snow fence vary slightly depending on the type of fence used. For Tensar\textsuperscript{TM} fences, a distance of at least 35 times their height is recommended between the road and the fence, while a distance of at least 25 times their height is recommended between rows (1). For plastic fences such as the ones used in Iowa, a distance of 30 times the height of the fence is suggested between the road and the fence, assuming level terrain and absence of trees and buildings (6). These results were confirmed by Brugnot (19) who compared the drifts obtained with 7 different fences made of synthetic material or wood, heights ranging from 5 to 7ft (1.5 to 2.1m), with or without bottom gaps, and also considering different slat orientations (horizontal or vertical). Drift lengths obtained for these structures ranged from 16 to 23 times the height of the fence. Finally, although fences should be placed perpendicular to the prevailing wind direction, Hurlbut (1) observed that departures of up to 20\degree did not seriously affect their performance. Finally, Tabler (13, 15, 16) concurred with most of these findings, recommending a general setback distance of 35 times the height of the fence for fences with 50\% porosity and bottom gap and reporting no serious effect on storage capacity for winds deviating up to 30\degree from the prevailing wind direction.

Studies similar to the one currently being conducted by the New Mexico Institute of Mining and Technology research team have been conducted in Canada, where, Rowan Williams Davies & Irwin Inc. (RWDI) analyzed snow drifting problems on 35 sites for the Ministry of Supply and Services Canada (20). Although permanent solutions were sought for several of the sites considered, their restricted budget and time frame only allowed for the development and testing of temporary snow fencing solutions. After initial site visits, weather information was collected for each site, including (1) mean snowfall, (2) wind direction with wind speeds greater than 15km/h (9mph), (3) direction of wind blowing snow, (4) winds greater than 15km/h (9mph) accompanying snowfall, (5) annual peak ground snow cover, (6) average number of days below 0\degree C (32\degree F) per winter month. A snow measuring procedure was also determined before field work initiation to assure consistent measurements. The procedure developed consisted in the use of a 12mm (0.5in) diameter pipe striped at 10cm (4in) intervals to probe the ground level at 1m (3ft) intervals from the snow fence to the edge of the road. Reference sites, similar to the studied area, were used to compare the effectiveness of the fences installed. Fence heights were determined by the methods developed by Ron Tabler. One of the products of this work was a flowchart created to help maintenance engineers solve common problems. This flowchart is reproduced in Figure 18. It consists of seven different steps which will be briefly discussed in the following. Step 1 consists in the determination of the type of problem experienced due to snow drifting, the three options presented are: poor visibility, loss of traction, and/or snow accumulation on the road. Step 2 involves the collection of meteorological data, including 4 year peak snowfall, prevailing wind direction and angle relative to the road, and average number of days per month when temperature drops below freezing. In step 3, information is collected on the critical characteristics of the surrounding terrain, such as vegetation, distance upwind to existing boundaries limiting the amount of snow approaching the study site, for example, fences, valleys, ravines, among others. In step 4, photographic examples compiled by the authors are used to match the problem in the area studied. Possible solutions are provided along with each
photographic example and should be considered in this step. Step 5 consists in the development of solutions using the information gathered in the previous steps. Graphs were developed by the authors to help determine the required number of rows and height of the snow fences to be installed. Step 6 provides proper installation details, while step 7 assures that monitoring is conducted to ensure effectiveness of solution adopted.

A management program for the snow fences is proposed to be used simultaneously with the design methodology described above (21). This program is referred to as D.I.M.E. which stands for Design, Install, Monitor and Evaluate and aims to provide cost effective snow fences as well as an evaluation tool that be used to justify the use or the discontinuation of snow fences. The design portion of this program follows the work described in Figure 18. The installation program included seminars to train the staff and considers spacing of fence posts, attachment of the fence to the upwind side of the post with appropriate ties, elevation of the fence above the ground, anchoring of the ends of the fence to assure proper tensioning, and anchoring of the sides of the fence to provide lateral resistance to overturning wind loads. Monitoring is to be conducted on a weekly basis as well as after each snow event. Check sheets are provided to the person inspecting the fence and information regarding the length of the drift observed, the amount of recent snowfall, the ground snow cover in adjacent fields, and the wind direction are recorded. In addition, the inspector is required to record any damage to the fence and any observations he or she may have regarding the performance of the system. If damage is observed, it should be repaired as soon as possible and records should include the nature of the damage observed and the type of repair performed. Proper documentation of the monitoring program is essential since it helps demonstrate maintenance procedures, assist in future decisions regarding the site, and protect from potential liabilities should accidents occur. The last component of this program is the evaluation portion which is conducted at the end of each winter. At this time, check sheets for each particular fence system are reviewed and the program is discussed to determine whether the same fences will be used the following winter, if modifications will be necessary, or if the use of snow fences will be completely discontinued.

It is important to note that snow fences are designed for prevailing wind direction and anticipated snow accumulation and as such, they are expected to be effective most of the time, not all of the time. In the instances where wind direction and/or snow accumulation vary from the norm, they may not only be ineffective in trapping snow, but they may also cause the formation of drifts in unexpected directions. Because snow fences should reduce drift formation on the roadways the majority of the time and such occurrences are expected to be rare, their adoption is recommended.
FIGURE 18 Snow Fence Placement Guidelines (20)
PHONE SURVEY

To determine commonly used snow fences among different states, Dr. Andrew Budek-Schmeisser and Mrs. Barbara Budek-Schmeisser contacted DOT officials in seven states: Idaho, Iowa, Minnesota, Montana, South Dakota, Utah, and Wyoming. Table 2 presents their main findings, while additional information is presented in the following.

TABLE 2 Snow Fence Use in Seven Different States

<table>
<thead>
<tr>
<th>State</th>
<th>Fences Used</th>
<th>Living Fences</th>
<th>Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iowa</td>
<td>Vertical lath fences</td>
<td>Corn rows and soybeans</td>
<td>Dennis Burkheimer 515-239-1355</td>
</tr>
<tr>
<td>Idaho</td>
<td>Plastic horizontal rail fences</td>
<td>Do not like them</td>
<td>Karen Hyatt 208-745-5601</td>
</tr>
<tr>
<td>Minnesota</td>
<td>Plastic horizontal rail fences</td>
<td>Extensively used</td>
<td>Dan Gulickson 952-758-7804</td>
</tr>
</tbody>
</table>
| Montana     | -Wyoming fences  
              -Plastic rail fences  
              -Wyoming fences with fiber reinforced polymer (FRP) rails | Trees and shrubs                     | Jon Swartz 406-444-6157     |
| South Dakota| -Temporary rollout fences  
              -Wyoming fences                                         | Pleased with results for over 20 years | Jason Humphrey 605-773-3571 |
| Wyoming     | -Wyoming fences  
              -Plastic rail fences  
              -Wooden rail fences  
              -Wood lath fences                                         | Used                                 | Kathy Alhenius 307-777-4264 |
| Utah        | -Wyoming fences  
              -Plastic horizontal rail fences  
              -Metal horizontal rail fences (old guardrails)         | Sage, rabbitbush, and one ridgetop location with trees as a test | Lynn Berhard 801-243-9642 (cell) |

Iowa

Permanent structural fences installed in Iowa are either made of vertical (as opposed to battered systems such as the Wyoming fence) wood laths or plastic strips. Their height is either 4 or 6ft (1.2 to 1.8 m). No gap is used at the bottom of these fences since laths tend to slide down over time and maintenance costs for these structures would be too high. Unfortunately 4ft (1.2m) fences are often buried during the winter, but the same was not observed with their 6ft (1.8m) counterpart. Landowners’ opposition to the larger structural fences prohibits their use.

Iowa also makes extensive use of living fences, particularly corn rows. In general, 6 to 8 rows of corn are left standing throughout the winter. Although they have been very effective in storing snow, instead of causing the formation of drifts downwind from the plants like a conventional
fence, the bulk of the snow is stored between the rows. For this reason, they can be set closer to the edge of the pavement than a structural snow fence. These “corn fences” have been successfully used on their own or combined with conventional snow fences at the edge of the right of way. Because of crop rotation, soybeans and sunflowers are also used as living fences.

Idaho

Idaho has used Ron Tabler’s expertise in analyzing selected problem areas, and experimented with different snow fence systems. The best results were obtained with vertical fence systems with wire-tensioned plastic horizontal strips. Idaho does not intend to adopt living fences because of the time required for the trees to mature and the fences to function effectively. In addition, the amount of work required to keep maturing living fences protected from deer, pests, and diseases, and the chance that not enough trees will survive to create an effective snow fence, render this alternative less attractive. Idaho has worked, and plans to continue to work closely with Wyoming and Montana in developing snow fence solutions. An innovative solution consisting in stacked hay bales is currently being tested by the state of Idaho.

Minnesota

Minnesota makes extensive use of living snow fences, not only in the form of new tree plantings, but also in preserving corn rows or native grasses and shrubs adjacent to a road. Because the use of living fences is seen in Minnesota as the best approach to the snow control problem, structural fences are only used where living fences are impractical, for example:

- Regions with herbicide concerns;
- Unavoidable title lines;
- Soil pH above 8.0;
- High soil salinity;
- Areas of excessive soil compaction;
- Areas with too much or too little moisture;
- Regions that are too rocky to permit normal root development;
- Deer wintering areas since excessive browsing prevents fences from reaching their required height.

Where structural fences are used, plastic horizontal rails are preferred.

Among the states surveyed, Minnesota was the only one having used condemnation to obtain access to private property for snow fence construction. In Dorow vs. The State of Minnesota (2003), the DOT won the right to condemn a strip of private land for snow fence placement because it would not only improve the safety of the traveling public, but it would also decrease state maintenance costs.

Montana

Montana uses both vertical fences with horizontal plastic rails and Wyoming fences. Although fiber reinforced polymer (FRP) rails were considered for use in the Wyoming fences, they were not as effective. Finally, trees and shrubs are also used in combination with the structural fences.
South Dakota

Snow fences are not commonly used in South Dakota. Structural fences used are either temporary rollout fences with vertical wood lath or plastic strips or permanent battered Wyoming fences. Where a landowner’s permission can be obtained, permanent fences are placed 100ft (30.5m) from the edge of the right of way. In these cases, the state usually negotiates temporary easements for the life of the structure. However, the preference is to allow the snow to be blown by the wind in the hope that it will blow across the roads.

Living snow fences have also been used in South Dakota. In these cases, 20-year contracts are signed with the landowners, where the state is responsible for growing the tress and erecting temporary fencing to protect and nurture them. Once the trees mature, they become the landowners’ property.

Wyoming

Wyoming closely follows the recommendations made by Ron Tabler in his numerous reports. Although wooden Wyoming A-frame fences were extensively used in the past, polyethylene Snow Predator fences made by Perma-Rail are now preferred (Figure 19). The primary reason for this shift is the very low maintenance costs of the newer systems. Wyoming fences on the other hand require constant maintenance since wooden slats shrink and bolts need to be retightened regularly. In addition, Wyoming barriers are typically held down by 1.2 m (4 ft) rebar stakes, which become loose over time and can lead to the loss of full panels. These problems are not present with the Snow Predator system which consists of polyethylene ribbons reinforced with 1.2mm (0.05in) cable and stretched between posts mounted in concrete. Both installation and maintenance costs for these fences are significantly lower. Material costs on the other hand are usually greater than that of wood fences, rendering Snow Predator’s initial cost higher. However, the minimal maintenance requirements of such fences have rendered them an attractive alternative.

Wyoming has also adopted living fences, and developed a protocol for their deployment, which consists of the construction of a cattle/deer fence to protect the seedlings and a structural fence to provide snow storage while the living fence matures as well as provide moisture for the maturing trees (Figure 20).

When snow fences are to be built on private property, the state acquires easements. To encourage landowners’ collaboration, additional advantages of these structures are showcased: provision of shelter for cattle (Figure 21) and wildlife (Figure 22), and increased watering of rangeland for cattle feed due to the accumulated snow. Although Wyoming never had to resort to condemnation to install snow fences, the state has considered the option.
FIGURE 19 Polyethylene Snow Fences - Wyoming

FIGURE 20 Living Snow Fence Protected by Structural Snow Fence – Wyoming
FIGURE 21 Cattle Sheltered by Snow Fence

FIGURE 22 Deer Sheltered by Snow Fence
Utah

Utah has been working closely with the state of Wyoming on controlling blowing snow. Utah has also been replacing their battered Wyoming fences with the Snow Predator systems. As Wyoming, Utah has tried to work with landowners without resorting to condemnation. Utah has also experimented with 1.2m (4ft) wooden lath and perforated plastic fences, as well as metal fences made from recycled guardrails. The wooden and plastic fences were found to be reasonably effective for limited snow collection requirements when a bottom gap of 200mm (8in) was provided. However, maintaining the gaps at the bottom of the lath fences has been particularly challenging since the laths dry out and drop through the wire loops that held them. The experience with the metal fences was not positive and they will not be used again; mainly because their porosity is too high, which makes them ineffective.

Living fences have also been considered in Utah. Of particular interest is a living fence placed at a ridgetop, which has been functioning well in keeping a road clear of snow drifts. In desert regions, sage and rabbitbush have been maintained as snow fences, and work effectively if the shoulder is kept clear, allowing the formation of drifts.

Utah plans to try out vortex generators developed by Rand Decker at Northern Arizona University. This strategy aims to reduce wind velocity at ground level and therefore limit snow transport. An example consists in spreading gravel on areas of the fetch to roughen the surface, reducing the amount of blowing snow in these regions.

VISIT TO THE WYOMING DEPARTMENT OF TRANSPORTATION

Because the state of Wyoming has extensive experience on the use of snow fences, two members of the NMT research team (Dr. Claudia Wilson and Mrs. Barbara Budek-Schmeisser) visited the WYDOT’s Winter Research Services, a team dedicated solely to extend the work conducted by Dr. Ron Tabler on the problems related to blowing snow. The visit was conducted on September 18, 2009 and led by Mrs. Kathy Ahlenius, who prepared a very instructive presentation on the Wyoming snow fences program, kindly answered all of our questions before, during and after the visit, and led us to sites where different types of snow fences were either in place or being constructed. A summary of the field visit is presented below.

The first site visited by the NMT research members was a test site on Interstate 25 where vertical fences using polymer rails (Perma-Rail’s Snow Predator) were installed alongside existing vertical wood fences and Wyoming barriers. After two winters, WyDOT personnel were very satisfied with the performance of the polymer fences and recommended that they be used instead of the Wyoming barriers and vertical wood fences. The main advantages of the polymer fences have been ease of installation and virtually no maintenance, which justify the higher initial cost. In fact, maintenance of the approximately 2900 snow fences in Wyoming is very labor intensive, and the Winter Research Team reports that a 4 men crew working for 3 months was only able to check anchors, tighten bolts and conduct small repairs on fences along a 13 mi (21km) stretch of road. In the two-year test period of the polymer fences, the only maintenance required consisted in a one-time tightening of the rails. Figures 23 to 26 present details of the polymer fences.
FIGURE 23 Polymer Snow Fence, I-25 Test Site, Wyoming

FIGURE 24 Details of Polymer Fence: (a) Post Channel, Rail, and Guide; (b) Ratchet
FIGURE 25 Anchoring of Polymer Fence Rails

FIGURE 26 Support Connection of Polymer Fence
As mentioned previously, also present at the test site were vertical wood fences. Two post shapes were being tested: round posts (Figure 27) and square posts (Figure 28). Splitting of the posts has been the biggest concern of the Winter Research Team, especially with respect to square posts. For this reason, round posts have been preferred and to facilitate the attachment of the horizontal members, one side of the round post is often flattened. Embedment length of the posts was being determined empirically: posts at the test site were embedded 8ft (2.4m), but WyDOT personnel believed this depth to be excessive and cited a successful smaller test section with an embedment length of only 4ft (1.2m). WyDOT Winter Research Team also recommended that screws be avoided since they are too brittle and break easily.
The last fence tested at the I-25 location was the Wyoming barrier. Although these structures were commonly used for several years, their maintenance requirements are rendering them obsolete. Most of the failures have been attributed to problems with the anchors which consist of 4ft (1.2m) rebars which often pull out (Figure 29) due to improper embedment, poor soil, or soil erosion. Although concrete anchors would work much better, as demonstrated in some locations, they would significantly increase the cost and labor required. Rocks have also been successfully used close to the anchors to weight down the fence and prevent the anchors from pulling out of the ground (Figure 30), but they may affect the effectiveness of the bottom gap.
Additional recommendations from the WyDOT Winter Research Team include:

- The use of shorter snow fences in conjunction with taller ones, especially at the ends of the fences where trapping efficiency of tall snow fences is severely reduced. In these instances, shorter fences can be used to extend the row of tall fences beyond the area to be protected, therefore maintaining the trapping efficiency and reducing the costs.

- Clearance of utility lines should also be considered since individuals may be tempted to use snowmobiles to ride over the drifts formed behind the snow fences.
Three sites were initially selected by members of the Technical Panel as candidates for test sites: (1) US 285, less than a mile south of the I-40 intersection in the region of Clines Corners (Figure 31), (2) US 64, immediately across from the Mountain View Cabins located at 28386 Hwy 64, Eagle Nest, NM (Figure 32), and (3) NM 434 between mileposts 24 and 25 in the region of Black Lake (Figure 33). Initial site visits were conducted to evaluate site conditions (adjacent land conditions, existing vegetation, surrounding terrain, accessibility, condition of existing snow fence, etc.) before the first snow fall of the season. Members of the Technical Panel accompanied the New Mexico Tech research team and offered detailed information on problems encountered in the past, measures attempted to solve the problem, and anticipated outcome of this research project. Dates of the visits were as follows: the Clines Corners region was visited on July 23, 2009, while the Eagle Nest and the Black Lake sites were visited on July 30, 2009.

FIGURE 31 Clines Corners’ Proposed Site – US 285, South of I-40 Intersection
FIGURE 32 Eagle Nest’s Proposed Site – US 64 (Critical Section between Arrows)

FIGURE 33 Black Lake’s Proposed Site – NM 434 South of NM 120 Intersection
A second set of site visits were conducted by the New Mexico Tech research team, this time with the sites under wintery conditions. The goal was to assess the performance of the existing snow fences, understand the magnitude of the problems encountered at these locations, and become familiar with the sites under snowy conditions. The Clines Corners site was visited on January 8, 2010 where a snow cover of only 0.25 to 0.5 in (0.6 to 1.3 cm) was observed on the fetch area and a very small drift had formed on the downwind side of the fence. For this reason, this site was visited again on January 31, 2010 when a ground cover of 7 in (17.8 cm) was observed in the fetch area and a drift of 1 ft-6 in to 1 ft-10 in (45.7 to 55.9 cm) was observed downwind of the snow fences.

The winter visit to the Eagle Nest site was conducted on January 29, 2010. During this visit, it was observed that not only did the snow accumulated on the downwind side of the fence already exceed the fence capacity, but additional snow displaced by plowing of the roads had helped fill the right-of-way. To increase snow storage capacity in the right-of-way, NMDOT personnel had created snow walls by driving trucks equipped with a steel wedge apparatus on the right-of-way. Height of the walls were found to be 4 ft-8 in to 5 ft (1.4 to 1.5 m), while drifts were found to reach 4 ft-6 in (1.4 m). Snow cover ranged from 5 to 7 in (12.7 to 17.8 cm).

The Black Lake site was visited on January 29, 2010. Unfortunately, the presence of a barbed wire fence between the snow fences and the road made it impossible to reach the snow fences placed in the straight sections of the road. However, a curved section between mileposts 24 and 25 was accessible and a maximum drift of 1 ft-6 in (45.7 cm) was observed at that location. Snow cover at the Black Lake location only reached 2 to 3 in (5.1 to 7.6 cm). Details of all field visits are reported in the following.

**SUMMER VISIT TO CLINES CORNERS SITE**

Dr. Andrew Budek-Schmeisser and Mrs. Barbara Budek-Schmeisser represented the research team at the first visit to the Clines Corners region on July 23, 2009. Below is a summary of their observations.

The fetch on the proposed site was found to be essentially infinite with gently rolling terrain (Figure 34). The critical section lies close to a shallow swale running approximately northwest-southeast. The adjacent land is owned by the state of New Mexico and leased for grazing. The vegetation on both the right of way and the state land to the northwest is grass. Grazing on the fetch area keeps grass cropped to the ground. The right of way is mowed adjacent to the pavement, but mowing does not extend to the fence location.

The existing snow fence is a 4 ft (1.2 m) vertical wood slat and wire fence that is contiguous with the right of way fence. Both are set back approximately 45 ft (13.7 m) from the pavement edge. The fence has a porosity of approximately 60% and no gap is maintained at the bottom. Prevailing wind is from the west-northwest and the fence is nearly perpendicular to the wind direction, which is considered ideal. However, NMDOT personnel report that it does not perform well. Storms coming from the east are usually the ones responsible for the formation of drifts at these locations. However, as the precipitation passes, the winds start to blow from the
west-northwest carrying the snow from the fetch and depositing in the roadway. Fences are often buried after the first couple of storms, and drifts will cross US285, requiring its closure. In fact, drifts as high as road signs have been observed in this location. Because plowing I-40 in the area is the main priority, drivers may have to wait 10 to 12 hours before US285 is plowed.

Based on information obtained from NMDOT, it appeared to the research team that although the fence orientation was correct, the 4ft (1.2m) fence was not high enough to provide the necessary storage capacity needed. In addition, it is placed very close to the pavement edge for a downwind storage drift to develop without encroaching on the roadway. Finally, the lack of a gap at the bottom of the fence is affecting its performance.

**WINTER VISIT TO CLINES CORNERS SITE**

Dr. Claudia Wilson visited the Clines Corners site in the afternoon (3 to 4PM) of January 31, 2010 to evaluate field conditions and existing snow fence performance under wintry conditions. Figure 35 depicts the region investigated with and without snow cover. Weather conditions on that day were as follows: partly cloudy skies, air temperature of 36°F (2.2°C), northwest sustained winds of 20mi/h (32.3km/h) with gusts of 25mi/h (40.2km/h). A snow cover of 7in (17.8cm) was measured in the fetch area. Snow fall for the month of January was estimated at 0.9in (2.3cm) of liquid equivalent (22), that is, approximately 9in (22.9cm) of snow (23). The average temperature for that month was 28.4°F (-2.0°C), with a high of 53.1°F (11.7°C) on January 12, and a low of 3.9°F (-15.6°C) on January 8, 2010. Average wind speeds for the month of January was 12.9knots or 14.9mi/h (24.0km/h), with the highest wind speed of 33knots or 38.0mi/h (61.1km/h) recorded on January 22, 2010 (22). West and northwest winds prevailed with gusts as high as 40knots or 46.0mi/h (74.1km/h) on January 24, 2010 (22).

During the visit, snow drifts could be observed along the extension of the fence as shown in Figure 36. A cross section of the system is also presented in Figure 37, showing the height of the drift, its distance from the fence, and the distance from the end of the drift to the edge of the pavement. Drift heights were found to vary between 1ft-6in (45.7cm) and 1ft-8in (50.8cm), while total drift lengths, measured perpendicular to the fence, were approximately 12ft (3.7m).
FIGURE 35 Proposed Test Site in the Clines Corners Region (Southwest View)

FIGURE 36 Snow Drift along Existing Snow Fence on US 285 (Southwest View)
FIGURE 37 Cross-Section of the Drift Observed in the Clines Corners Region (01/31/10). Drawing Not to Scale. (1ft = 30.48 cm; 1 in = 2.54 cm)

The effects of vegetation present along the fence can also be observed on Figures 38 and 39. It can be seen that the small shrubs growing adjacent to the fence helped with the snow storage, increasing the height and the length of the drifts at these locations. It is also interesting to notice that the drifts stretched in the southeast direction and not in the east direction which is perpendicular to the snow fence. This is because on the day of the visit (January 31, 2010) as well as on the days immediately preceding the field visit (January 29 and 30, 2010) prevailing winds came from the northwest. Horizontal distances measured immediately downwind from the shrubs in the northwest-southeast direction, from the fence to the highest point of the drift, reached 12ft (3.7m). Total drift lengths in these regions ranged from 14 to 16ft (4.3 to 4.9m). Drift heights in these locations ranged from 1ft-8in to 1ft-10in (50.8 to 55.9cm).

FIGURE 38 Drift Formed Downwind from Shrub (Northwest View)
ACCIDENT REPORTS FOR CLINES CORNERS SITE

From January 01, 2003 to December 31, 2008, eight accidents were reported between mileposts 246 and 248 on US 285 in the region of Clines Corners. A brief description of these accidents is presented in Tables 3 and 4, including date, time, severity, weather conditions, accident classification, brief description, number of vehicles involved, drivers’ sobriety, and contributing factors to the accident. Of the eight accidents in the area, only two listed wintry conditions. The first one happened on January 04, 2007, at milepost 247.9, and consisted in the sideward collision of a passenger vehicle and a vehicle classified as a truck or recreational vehicle traveling on south on the snowy road. The accident happened at 10:30 AM, under windy conditions. Contributing to the accident was the fact that the driver of the passenger vehicle driver was inattentive and driving too fast for the conditions. The only other accident listing wintry conditions happened two days later, on January 06, 2007 when a truck or recreational vehicle traveling north on the icy road overturned on milepost 246. The accident happened at 7:33 PM, under dark conditions. Weather conditions were listed as windy. Also contributing to this accident were vehicle speed too high for conditions, and driver inattention.
TABLE 3 Summary of Accidents Occurring between Mileposts 246 and 248 on US 285 in the Clines Corners Area (01/01/03 to 09/30/03). Highlighted Rows Indicate Accidents that Occurred under Wintery Conditions.

<table>
<thead>
<tr>
<th>Milepost</th>
<th>Date and Time</th>
<th>Severity</th>
<th>Lighting</th>
<th>Weather</th>
<th>Classification</th>
<th>Analysis</th>
<th>Vehicle 1</th>
<th>Vehicle 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>245.9</td>
<td>03/13/03 1445</td>
<td>Non-fatal (injury)</td>
<td>Day light</td>
<td>Clear</td>
<td>Other vehicle</td>
<td>One left turn enter at angle</td>
<td>Truck/RV</td>
<td>Passenger vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Traveling south on dry road</td>
<td>Traveling north on dry road</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Failed to yield ROW</td>
<td>No contributing factors</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Driver inattention</td>
<td>1 injured</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 injured</td>
<td></td>
</tr>
<tr>
<td>246</td>
<td>08/20/04 1430</td>
<td>Property damage only</td>
<td>Day light</td>
<td>Raining</td>
<td>Overturn</td>
<td>Right side road</td>
<td>Truck/RV</td>
<td>Passenger vehicle</td>
</tr>
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<td></td>
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<td>Traveling north on wet road</td>
<td>Traveling north on dry road</td>
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<td></td>
<td></td>
<td></td>
<td>Driver inattention</td>
<td>No contributing factors</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Other improper driving</td>
<td>1 injured</td>
</tr>
<tr>
<td>246</td>
<td>01/06/07 1933</td>
<td>Property damage only</td>
<td>Dark (not lighted)</td>
<td>Clear</td>
<td>Overturn</td>
<td>Left side road</td>
<td>Truck/RV</td>
<td>Passenger vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Traveling north on icy road</td>
<td>Traveling south on dry road</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Had not consumed alcohol</td>
<td>Had not consumed alcohol</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Too fast for conditions</td>
<td>No contributing factors</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Driver inattention</td>
<td>1 injured</td>
</tr>
<tr>
<td>246.1</td>
<td>11/07/05 2000</td>
<td>Property damage only</td>
<td>Dark (not lighted)</td>
<td>Clear</td>
<td>Animal</td>
<td>Deer</td>
<td>Truck/RV</td>
<td>Passenger vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Traveling south on dry road</td>
<td>Traveling north on dry road</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Had not consumed alcohol</td>
<td>Had not consumed alcohol</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Avoid no contact with pedestrian or animal</td>
<td>Avoid no contact with pedestrian or animal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Traffic control not functioning</td>
<td>Traffic control not functioning</td>
</tr>
<tr>
<td>246.1</td>
<td>05/10/06 2215</td>
<td>Property damage only</td>
<td>Dark (not lighted)</td>
<td>Clear</td>
<td>Animal</td>
<td>Deer</td>
<td>Truck/RV</td>
<td>Passenger vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Traveling north on dry road</td>
<td>Traveling south on dry road</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Had not consumed alcohol</td>
<td>Had not consumed alcohol</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Avoid no contact with pedestrian or animal</td>
<td>Avoid no contact with pedestrian or animal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Traffic control not functioning</td>
<td>Traffic control not functioning</td>
</tr>
<tr>
<td>246.2</td>
<td>09/30/03 820</td>
<td>Property damage only</td>
<td>Day light</td>
<td>Clear</td>
<td>Animal</td>
<td>Deer</td>
<td>Truck/RV</td>
<td>Passenger vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Traveling south on dry road</td>
<td>Traveling north on dry road</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Had not consumed alcohol</td>
<td>Had not consumed alcohol</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Avoid no contact with pedestrian or animal</td>
<td>Avoid no contact with pedestrian or animal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Other not driver error</td>
<td>1 injured</td>
</tr>
</tbody>
</table>
TABLE 4 Summary of Accidents Occurring between Mileposts 246 and 248 on US 285 in the Clines Corners Area (10/01/03 to 12/31/08). Highlighted Rows Indicate Accidents that Occurred under Wintery Conditions.

<table>
<thead>
<tr>
<th>Milepost</th>
<th>Date and Time</th>
<th>Severity</th>
<th>Lighting</th>
<th>Weather</th>
<th>Classification</th>
<th>Analysis</th>
<th>Vehicle 1</th>
<th>Vehicle 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>247.9</td>
<td>01/04/07 1030</td>
<td>Property damage</td>
<td>Day light</td>
<td>Wind</td>
<td>Other vehicle</td>
<td>Sideswipe collision same direction</td>
<td>Passenger vehicle Traveling south on snowy road Had not consumed alcohol Too fast for conditions Driver inattention</td>
<td>Truck/RV Traveling south on snowy road Had not consumed alcohol Veh. skidded before brake</td>
</tr>
<tr>
<td>248.02</td>
<td>10/19/07 415</td>
<td>Property damage</td>
<td>Dark (not lighted)</td>
<td>Clear</td>
<td>Animal</td>
<td>Deer</td>
<td>Trailer/freight Traveling north on dry road Had not consumed alcohol Avoid no contact with pedestrian or animal Traffic control not functioning</td>
<td></td>
</tr>
<tr>
<td>246.2</td>
<td>09/30/03 820</td>
<td>Property damage</td>
<td>Day light</td>
<td>Clear</td>
<td>Animal</td>
<td>Deer</td>
<td>Truck/RV Traveling south on dry road Had not consumed alcohol Avoid no contact with pedestrian or animal Other not driver error</td>
<td></td>
</tr>
<tr>
<td>247.9</td>
<td>01/04/07 1030</td>
<td>Property damage</td>
<td>Day light</td>
<td>Wind</td>
<td>Other vehicle</td>
<td>Sideswipe collision same direction</td>
<td>Passenger vehicle Traveling south on snowy road Had not consumed alcohol Too fast for conditions Driver inattention</td>
<td>Truck/RV Traveling south on snowy road Had not consumed alcohol Veh. skidded before brake</td>
</tr>
<tr>
<td>248.02</td>
<td>10/19/07 415</td>
<td>Property damage</td>
<td>Dark (not lighted)</td>
<td>Clear</td>
<td>Animal</td>
<td>Deer</td>
<td>Trailer/freight Traveling north on dry road Had not consumed alcohol Avoid no contact with pedestrian or animal Traffic control not functioning</td>
<td></td>
</tr>
</tbody>
</table>
SUMMER VISIT TO EAGLE NEST SITE

Dr. Claudia Wilson and Mrs. Barbara Budek-Schmeisser visited the prospective Eagle Nest site on July 30, 2009. According to NMDOT personnel, snow drifts have been observed in more than one location in that region from December to April, but the most critical site and the one selected for analysis in this project is immediately across from the Mountain View Cabins which are located at 28386 US Hwy 64, Eagle Nest, NM. The terrain in the Eagle Nest region is mountainous, but the region of interest is located in a valley. The land upwind from the right-of-way is used for grazing. Two types of fences can be found at that location, as shown in Figure 40, one is a 4ft (1.2m) high barbed wire fence that extends north, and the other is a 4ft (1.2m) tall snow fence that extends south. The snow fence is made of vertical wood slats. Although the fences were built with a gap of 5in (12.7cm) from the ground, shrinking of slats due to weather effects caused them to slide down, closing the gap. Like the site selected in the Clines Corners region, the fetch at this site is also essentially infinite, that is, it extends farther than the distance that a snow particle can travel without evaporating. The distance from the fence to the edge of the pavement is larger than that at the Clines Corners site, reaching 75ft (22.9m) at that location.

FIGURE 40 Eagle Nest Proposed Site (West View)

WINTER VISIT TO EAGLE NEST SITE

Dr. Claudia Wilson visited the Eagle Nest site in the afternoon (3 to 4PM) of January 29, 2010 to evaluate field conditions and existing snow fence performance under wintery conditions. Figure
41 depicts the region investigated with and without snow cover. The weather conditions on that day were as follows: clear skies, air temperature of 33°F (0.6°C), no wind. A snow cover ranging from 5 to 7in (12.7 to 17.8cm) was measured in the fetch area. At that time, not only did the snow accumulated on the downwind side of the fence already exceed the fence capacity, but additional snow displaced by plowing of the roads had helped fill the right-of-way. This was actually expected for this region because the cold temperatures observed during the winter months prevent accumulated snow from melting before the end of the winter. Data presented in www.climate-charts.com (24) list average maximum and minimum temperatures for this region based on data collected by the National Oceanic and Atmospheric Administration (NOAA) from 1971 to 2000. Maximum temperatures have averaged 47.5°F (8.6°C) for the months of November during this 29 year period, while in December and January, they have only averaged 39°F (3.9°C), and 37.4°F (3°C), respectively. Although February maximum temperatures were a little higher, they only averaged 41.2°F (5.1°C). Average minimum temperatures were also very low at Eagle Nest, averaging 14.2°F (-9.9°C) in November, 4.1°F (-15.5°C) in December, 0.9°F (-17.3°C) in January, and 6.1°F (-14.4°C) in February (24).

In an attempt to increase snow storage capacity in the right-of-way, NMDOT personnel have been creating snow walls by driving trucks equipped with a steel wedge apparatus on the right-of-way. Figures 42 and 43 show snow walls created on this section of Hwy 64. As can be seen in Figure 44, the height of these walls exceeds 4ft (1.2m), which is the height of the snow fences currently installed in this section of the road. Also of interest is the fact that the construction of the walls disturbs the drifts originally created on the downwind side of the fence. Nevertheless, measurements were made to assess the current conditions of the site. Depth of the drift formed close to the fence was measured, as were depths of the snow wall that followed. Figure 45 presents the drift created closest to the fence due to snow deposited by the wind as it struck the snow fence and snow displaced by the NMDOT to create snow walls. Figure 46 presents a schematic of the cross section of the system observed immediately in front of the Mountain View Cabins on Hwy 64.

(a) Summer 2009 (b) Winter 2010

FIGURE 41 Proposed Test Site in the Eagle Nest Region (West View).
FIGURE 42 Snow Walls Created by NMDOT Parallel to Existing Snow Fences (Southwest View)

FIGURE 43 Snow Walls Created to Increase Storage Capacity on Right-of-Way (South View)
FIGURE 44 Snow Drift and Snow Walls on Downwind Side of Snow Fence (South View)

FIGURE 45 Cross-Section of the Drift and Snow Wall Observed at the Eagle Nest Site, across from the Mountain View Cabins on Hwy 64. Drawing Not to Scale. (1ft = 30.48cm; 1in = 2.54cm)
Approximately half a mile south of the Mountain View Cabins on Hwy 64, a small section of the snow fences were found to have undisturbed snow drifts. Figure 46 illustrates this small section, and shows that the height of the drift is at least equal to the height of the snow fence. A schematic of the cross section of this system is presented in Figure 47.

**FIGURE 46 Undisturbed Drift Section on Highway 64, Half-Mile South of the Mountain View Cabins (Northwest View)**

**FIGURE 47 Cross-Section of the Undisturbed Drift Observed at the Eagle Nest Site, Half-Mile South of the Mountain View Cabins on Hwy 64. Drawing Not to Scale. (1ft = 30.48cm; 1in = 2.54cm).**
ACCIDENT REPORTS FOR EAGLE NEST SITE

Twelve accidents were reported from January 01, 2003 and December 31, 2008 around mileposts 284 and 285 of US 64 in the region of Eagle Nest. Of these twelve accidents, three cited wintery conditions. The first one occurred on February 25, 2003, on milepost 283.6, at 9:30 PM, under snowing conditions. The driver of a truck or recreational vehicle was traveling east on the icy road at excessive speed, overturned the vehicle. In addition to excess speed, driver inattention, and speed too high for conditions were listed as contributing factors. The accident happened at night (9:30 PM) in an area that is not lit. According to weather reports for the area collected by Mr. Ernest Sutliff for the Weather Forecast Office of Albuquerque, snow fall for that day was 1.5in (3.8cm). Snow records for the month of February of 2003 (before the 25th) were as follows: 4.5in (11.4cm) on February 6, 5.5 in on February 7, 4in (10.2cm) on February 15, 4in (10.2cm) on February 16, and 1in (2.5cm) on February 19. High temperatures between 02/06/09 and 02/25/09 varied significantly, reaching 49°F (9.4°C) on February 13 and again on February 22.

The second accident listing wintery conditions happened on November 30, 2006 and involved four vehicles: two trucks or recreational vehicles and two passenger cars. The accident happened at 1:20 PM of a clear day, but on a snowy road. In this accident, the driver of a truck or recreational vehicle was traveling east when the vehicle spun on the roadway and was hit by another truck or recreational vehicle traveling west and going too fast for the present conditions. The driver of the truck traveling west was also claimed to be inattentive. Two passenger cars were also traveling west behind the truck and were not able to stop. Drivers of these vehicles were also inattentive, driving too fast for the conditions, and following too close. According to weather records, this was the only snow event in the month of November of 2006. Two inches (5.1cm) of snow were recorded the day before the accident and 2.5in (6.4cm) on the day of the accident.

The last accident occurred at 2:21 PM on December 20, 2006, a clear day. At that time, the road was snowy and a passenger car traveling east once again going too fast for the conditions overturned on the road at milepost 283.05. Driver inattention also contributed to the accident. Snowfall was also observed on the day of this accident. Snow records indicate a total of 5.5in (14cm) of snow on that day. Snowfall for the month of December of 2006 previous to the accident are as follows: 5.5in (14cm) on December 3, 1.5in (3.8cm) on December 11, and 1in (2.5cm) on December 19. Although high temperatures for that month ranged from high thirties to low forties (degrees Fahrenheit), December 17 saw a high of 50°F (10°C).

Although the accidents mentioned above occurred during snow events, it is important to note that these were not the only storms that occurred during the period studied, nor were they the most severe storms recorded. For example, a few days after the accident of December 20, 2006, snowfall records indicate 8in (20.3cm) of snow on December 29, 9 in on December 30, and 16in (40.6cm) on December 31.
### TABLE 5 Summary of Accidents Occurring between Mileposts 284 and 285 on US Hwy 64 in the Eagle Nest Area (01/01/03 to 06/27/03). Highlighted Rows Indicate Accidents that Occurred under Wintery Conditions.

<table>
<thead>
<tr>
<th>Milepost</th>
<th>Date and Time</th>
<th>Severity</th>
<th>Lighting</th>
<th>Weather</th>
<th>Classification</th>
<th>Analysis</th>
<th>Vehicle 1</th>
<th>Vehicle 2</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>283</td>
<td>11/23/03 1959</td>
<td>Non-fatal (injury)</td>
<td>Dark (lighted)</td>
<td>Clear</td>
<td>Animal</td>
<td>Elk</td>
<td>Passenger vehicle</td>
<td></td>
<td>Traveling east on dry road Had not consumed alcohol Driver inattention 1 injured</td>
</tr>
<tr>
<td>283</td>
<td>08/14/05 2200</td>
<td>Property damage only</td>
<td>Dark (not lighted)</td>
<td>Clear</td>
<td>Animal</td>
<td>Elk</td>
<td>Truck/RV</td>
<td></td>
<td>Traveling west on dry road Had not consumed alcohol Avoid no contact with pedestrian or animal Traffic control not functioning</td>
</tr>
<tr>
<td>283.05</td>
<td>12/20/06 1421</td>
<td>Property damage only</td>
<td>Day light</td>
<td>Clear</td>
<td>Overturn</td>
<td>On the road</td>
<td>Passenger vehicle</td>
<td></td>
<td>Traveling east on snowy road Had not consumed alcohol Too fast for conditions Driver inattention</td>
</tr>
<tr>
<td>283.42</td>
<td>04/11/06 2315</td>
<td>Property damage only</td>
<td>Dark (not lighted)</td>
<td>Clear</td>
<td>Animal</td>
<td>Elk</td>
<td>Trailer/freight</td>
<td></td>
<td>Traveling east on dry road Had not consumed alcohol Avoid no contact with pedestrian or animal Traffic control not functioning</td>
</tr>
<tr>
<td>283.6</td>
<td>02/25/03 2130</td>
<td>Property damage only</td>
<td>Dark (not lighted)</td>
<td>Snowing</td>
<td>Overturn</td>
<td>Right side road</td>
<td>Truck/RV</td>
<td></td>
<td>Traveling east on icy road Had not consumed alcohol Excess speed Too fast for conditions Driver inattention</td>
</tr>
<tr>
<td>283.9</td>
<td>06/27/03 1925</td>
<td>Property damage only</td>
<td>Day light</td>
<td>Clear</td>
<td>Other vehicle</td>
<td>Sideswipe collision from opposite direction</td>
<td>Truck/RV</td>
<td></td>
<td>Traveling east on dry road Had not consumed alcohol Drive left of center Driver inattention</td>
</tr>
</tbody>
</table>


### TABLE 6 Summary of Accidents Occurring between Mileposts 284 and 285 on US Hwy 64 in the Eagle Nest Area (06/28/03 to 11/30/06). Highlighted Rows Indicate Accidents that Occurred under Wintery Conditions.

<table>
<thead>
<tr>
<th>Milepost</th>
<th>Date And Time</th>
<th>Severity</th>
<th>Lighting</th>
<th>Weather</th>
<th>Classification</th>
<th>Analysis</th>
<th>Vehicle 1</th>
<th>Vehicle 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>284</td>
<td>08/17/05 2337</td>
<td>Property damage only</td>
<td>Dark (not lighted)</td>
<td>Clear</td>
<td>Animal</td>
<td>Elk</td>
<td>Truck/RV</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Traveling west on dry road</td>
<td>Had not consumed alcohol</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Avoid no contact with pedestrian or animal</td>
<td>Traffic control not functioning</td>
<td></td>
</tr>
<tr>
<td>284.3</td>
<td>03/07/04 300</td>
<td>Non-fatal (injury)</td>
<td>Dark (not lighted)</td>
<td>Clear</td>
<td>Overturn</td>
<td>Left side road</td>
<td>Truck/RV</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Traveling south on dry road</td>
<td>Had not consumed alcohol</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Excess speed</td>
<td>Driver inattention</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 injuries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>284.8</td>
<td>03/18/05 2110</td>
<td>Property damage only</td>
<td>Dark (not lighted)</td>
<td>Clear</td>
<td>Animal</td>
<td>Cattle</td>
<td>Truck/RV</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Traveling east on dry road</td>
<td>Had not consumed alcohol</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Avoid no contact with pedestrian or animal</td>
<td>Other not driver error</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>285.2</td>
<td>11/30/06 1320</td>
<td>Property damage only</td>
<td>Day light</td>
<td>Clear</td>
<td>Other vehicle</td>
<td>Opposite direction – one veh. Spun on road before being hit</td>
<td>Vehicle 1</td>
<td>Vehicle 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Truck/RV</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Traveling east on snowy road</td>
<td>Had not consumed alcohol</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Vehicle skidded before brake</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Vehicle 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Passenger vehicle</td>
<td>Traveling west on snowy road</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Had not consumed alcohol</td>
<td>Too fast for conditions</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Following too close</td>
<td>Driver inattention</td>
<td></td>
</tr>
</tbody>
</table>

47
TABLE 7 Summary of Accidents Occurring between Mileposts 284 and 285 on US Hwy 64 in the Eagle Nest Area (12/01/06 to 12/31/08). Highlighted Rows Indicate Accidents that Occurred under Wintery Conditions.

<table>
<thead>
<tr>
<th>Milepost</th>
<th>Date And Time</th>
<th>Severity</th>
<th>Lighting</th>
<th>Weather</th>
<th>Classification</th>
<th>Analysis</th>
<th>Vehicle 1</th>
<th>Vehicle 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>285.75</td>
<td>06/25/03 1800</td>
<td>Property damage only</td>
<td>Day light</td>
<td>Clear</td>
<td>Other vehicle</td>
<td>One car/enter driveway acc. Truck/RV Traveling east on dry road Had not consumed alcohol Failed to yield ROW Driver inattention</td>
<td>Truck/RV Traveling east on dry road Had not consumed alcohol No other contributing factor</td>
<td></td>
</tr>
<tr>
<td>286</td>
<td>11/12/05 2244</td>
<td>Property damage only</td>
<td>Dark (not lighted)</td>
<td>Clear</td>
<td>Animal</td>
<td>Dog Passenger vehicle Traveling west on dry road Had not consumed alcohol Avoid no contact with pedestrian or animal Traffic control not functioning</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
WINTER VISIT TO BLACK LAKE SITE

Black Lake has also been considered as an alternative site for the Eagle Nest region. For this reason, Dr. Claudia Wilson conducted a field visit of the site on January 29, 2010. The section considered is located on NM 434, between mileposts 24 and 25, as shown in Figure 48.

FIGURE 48 Barbed-Wire Fence and Snow Fences Installed Parallel to NM 434 in the Black Lake Region (Northwest View)

At this location, 4ft (1.2m) tall snow fences made of vertical wood slats with no gap at the bottom were installed parallel to the road. As with the other proposed sites, the fetch in this region is essentially infinite. Due to the presence of a barbed wire fence between the snow-fences and the road, the distance between the fence and the edge of the pavement could not be measured, but, as shown in Figure 49, the fence is significantly farther from the road than the fences on Hwy 64.

The field evaluation visit was conducted during the afternoon (4:30 to 5:30 PM) of January 29, 2010. The weather conditions on that day were similar to those described for the Eagle Nest region: clear skies with no wind, but due to the later time, air temperatures were a little colder: 25°F (-3.89°C). The snow cover was not as deep as in Eagle Nest, only ranging from 2 to 3in (5.1 to 7.6cm). Although drifts could be seen on the downwind side of the fences, as shown in Figure 49, measurements were not possible on the straight sections of the road due to the barbed wire fence preventing access to the system. The only accessible site was a curved section located between mileposts 24 and 25. Although the drift present at that location was quite small (Figures 50 and 51), its dimensions were recorded. The maximum depth of the drift was 1ft-6in (45.7cm), at a horizontal distance of 8ft (2.4m) from the fence. The total length of the drift varied from 8 to 12ft (2.4 to 3.7m).
FIGURE 49 Snow Drifts in Front of Snow Fences Installed on NM 434 in the Black Lake Region (Northwest View)

FIGURE 50 Snow Drift in Curved Section of NM 434 between Mileposts 24 and 25 in the Black Lake Region (South View)
FIGURE 51 North View of the Snow Drift between Mileposts 24 and 25 on NM 434 in the Black Lake Region
TASK 3 – DEVELOPMENT OF A METHODOLOGY FOR LEGAL AND SAFETY ISSUES

Task 3 consists in researching and documenting legal precedent for the placement of safety structures such as snow fences on private land. Although extreme measures such as easement condemnation should be avoided, precedent for such action is also to be investigated. Safety issues are to be examined during this task.

Mrs. Barbara Budek-Schmeisser and Dr. Andrew Budek-Schmeisser were responsible for most of the research conducted for this task. Their findings are presented in the sections entitled: “Eminent Domain”, “NMDOT Practice in Obtaining Access for Snow Fence Construction and Maintenance”, and “DOT Responsibility for Safety Issues”. Finally, recommendations on the process to be followed for placement of snow fences on private land were developed by Dr. Claudia Wilson and Mrs. Barbara Budek-Schmeisser.

EMINENT DOMAIN

Legal issues in snow barrier deployment consist mainly of problems with uncooperative landowners who oppose the construction of snow barriers on their land. To determine the most successful approaches to uncooperative landowners, DOT officials from other states have been contacted. The most common approach has been to obtain landowners’ cooperation by showcasing the benefits of the snow fences not only to traffic safety, but also to grazing operations. This is because not only do these structures provide shade for the animals during the summer months, but they also provide shelter during the winter and by trapping snow, they assist with the watering of the rangeland. Minnesota seems to be the only state that has had to resort to condemning land for the construction of snow fences.

The issue of eminent domain is rather polemic and has a history of highly visible cases. A recent one is Kelo v. City of New London which, in 2005, was decided in favor of the defendant by the Supreme Court. In this case, a group of landowners brought suit against the city, when city development officials condemned residential property to allow for the development of privately funded revenue-producing property. The decision against the plaintiffs was based largely on precedent. Of particular importance were the landmark cases of Berman v. Parker (1954) and Hawaii Housing Authority v. Midkiff (1984). In Berman v. Parker, the Supreme Court allowed the department store owned by the plaintiff to be transferred to private developers even though the property itself was not blighted. The reasoning was that the taking of such property was necessary to successfully implement a redevelopment plan and clear blight from the entire area around said property. In the second landmark case, Hawaii Housing Authority v. Midkiffe, private land was redistributed because the concentration of land ownership was considered by the State of Hawaii to be negatively affecting public welfare.

Also of interest, is 225 Front Street, Ltd. v. City of Binghamton (NY), which was decided in 2009. In this case, part of a private property was condemned to widen the radius of an intersection. The landowner argued against the condemnation, claiming that the road would mainly serve commercial vehicles and bring no public benefit. The court decided against the
plaintiff maintaining that the project would improve traffic by providing an adequate turning radius at the intersection in question.

A special application of eminent domain relates to the condemnation of easements. This is usually a simpler process since it relates to land use instead of landownership. However, requirements for compensation are not as clearly defined and vary from state to state. Although some states mentioned during the phone interviews that condemnation has been considered, most try to avoid it by showing landowners the advantages brought by the snow fences.

**NMDOT PRACTICE IN OBTAINING ACCESS FOR SNOW FENCE CONSTRUCTION AND MAINTENANCE**

On September 10, 2009, Dr. Andrew Budek-Schmeisser and Mrs. Barbara Budek-Schmeisser met with Mr. Bill Moyers and Ms. Cheryl O’Connor from the NMDOT Office of General Counsel to learn about NMDOT practices in obtaining access to private land for construction and maintenance of snow fences as well as the NMDOT’s position on condemnation. This section summarizes the information obtained during said meeting.

For optimum performance, snow fences have to be placed a considerable distance from the edge of the pavement, often beyond the right-of-way fence. In some areas, the fence will need to be located on private land. Because NMDOT personnel may need constant access to the fence location, for construction, maintenance and at a later date, replacement, the favored approach has been the granting of an easement. In this case, the landowner receives an agreed-upon compensation and retains the title of the land, while NMDOT personnel are granted permission to work in a specified area of the property. This agreement can often be reached once the landowner understands the advantages of the snow fences to public safety, with the added bonus of providing shade and shelter for cattle, and increasing snow storage and hence soil moisture for the growth of forage for livestock.

If the landowner is uncooperative, condemnation may be considered. In fact, in 2003, condemnation was successfully used for snow fence construction in Minnesota. In State of Minnesota v. David Dorow et al, the Brown County Court of Appeals upheld a district court ruling that the state’s purpose of improving traveling public safety was a legitimate use of the condemnation process and allowed for the removal of a group of trees on Dorow’s property and the construction of a snow fence at that location.

**NMDOT RESPONSIBILITY FOR ROAD SAFETY**

During the meeting of September 10, 2009, Mr. Bill Moyers and Ms. Cheryl O’Connor from the NMDOT Office of General Council also mentioned another legal question to be considered, that of the state’s responsibility for road safety. Although sovereign immunity allows states to decline lawsuits against them, a state can be sued if so determined by federal courts. In fact, this has happened in several instances in New Mexico and failure to comply with roadway safety standards established by the National Cooperative Highway Research Program (NCHRP) may
lead to yet another case whether sovereign immunity may not be used. This is because a federally-developed safety standard is likely to supersede state guidelines.

RECOMMENDED APPROACH FOR PLACING SNOW FENCES ON PRIVATE LAND

Because snow fences have been shown to improve public safety by effectively reduce drift formation on the roadways the majority of the time, their adoption is highly recommended by the research team. Although in some instances other measures may be taken to improve snow accumulation on the roadway, they usually involve more elaborate procedures that are often cost-prohibitive or that may be faced with even more protest from the landowners. For example, in some cases, changes to the profile of the land close to the roadway may lead to favorable results. However, cutting and filling these areas may not be financially or physically feasible. Therefore, the placement of snow fences is often a cost-effective choice. Nevertheless, landowners’ opposition to the placement of these structures on their land is not uncommon. In these cases, the best approach is to seek landowners’ endorsement by stressing the additional advantages of these structures: shelter and shade for cattle and wildlife and increased watering of rangeland for cattle feed due to the accumulated snow. This approach has been effective in other states and as mentioned previously, only Minnesota had to resort to condemnation. For this reason a comprehensive program like the Iowa Cooperative Snow Fence Program (11, 12) which recommends a variety of solutions to drifting snow such as: permanent and temporary structural fences, standing corn rows, living trees, shrubs, or native grasses, or Conservation Reserve Program (CRP) living snow fences may not be necessary.

After snow fences have been selected as the best solution for a problematic site and their design has been completed, the following steps should be taken for acquiring the land necessary for their placement:

1. Determine the area necessary for construction of the fences and for access and maintenance of the structures. Because construction of the barriers requires the use of a larger area than their general maintenance, an agreement could be made to grant temporary access to a predetermined area for storing construction material and maneuvering vehicles, while a smaller, more permanent easement could be obtained for maintenance purposes. The latter would include access from the roadway to the fences as well as a small area surrounding the structures to give maintenance crew enough room to work.

2. Contact the Right-of-Way Bureau Chief requesting a Title Report.

3. Contact the Right-of-Way Bureau and provide:
   a. Detailed information on the snow fences to be constructed,
   b. Maps showing the location of the proposed fences and easements required,
   c. Title of the land,
   d. Final maps and legal descriptions or Plats,
   e. Appraisal of the land.
A meeting will be set up with the landowner or lessee to discuss the possibility of an agreement. Details of the process are presented in the Right-of-Way Handbook available online at the NMDOT website (http://dot.state.nm.us/Infrastructure/ROW_Handbook.pdf)
TASK 4 – ANALYSIS METHOD FOR DETERMINATION OF CRITICAL SITE PARAMETERS

Unfortunately, the cost of designing and even more so of constructing and maintaining snow fences may prevent their use along extensive sections of roadways. This is particularly true when larger structures, that is, snow fences of 8ft (2.4m) or more in height, are required. Also of concern is the reluctance of landowners to allow the placement of these structures in their properties. Therefore, it is essential to carefully select the locations where snow fences are absolutely necessary to ensure public safety and reduce plowing costs.

PARAMETERS INFLUENCING THE DECISION OF ADOPTING SNOW FENCES

Dr. Andrew Budek-Schmeisser was responsible for investigating and prioritizing site and environmental parameters influencing the decision of adopting snow fences to reduce the formation of snow drifts on a roadway. According to his research, this decision should be based on the following factors:

1. the number of accidents, in the previous 5 years, listing snowdrift or ice on the roadway as a contributing factor;
2. the number of road closures due to snowdrift of ice on the roadway in the previous 5 years;
3. the extensive need for plowing in the area;
4. a history of snow drift formation on the roadway.

Clearly, sites with a high number of accidents listing snowdrift or ice on the roadway as contributing cause should be considered as candidates for the use of snow fences. However, in these cases, all other factors contributing to the accidents should also be considered because the reduction of snow accumulation and ice formation on the roadway alone may not be sufficient to significantly reduce the number of accidents at that location. Furthermore it is recommended that accident records for the previous 5 years be obtained because the amount of snow fall can dramatically change from year to year. Sites with a history of road closures due to snowdrifts or ice on the road and sites with frequent plowing requirements are also to be considered as candidates for the placement of snow fences. Priority should be given based on the seriousness of the problem, that is, the number and severity of accidents, the frequency and duration of road closures, and the extent of plowing requirements. Route’s importance to the region and average daily traffic (ADT) should also be considered.

SNOW FENCE SELECTION

Once snow fences have been considered for a particular site, meteorological data and topographical data should be collected, as described in Task 6 – Match Analysis Methodology, to determine the necessary storage capacity of the fences and hence their required height and the ideal location for their placement, the two most important parameters dictating the effectiveness of these structures. As mentioned in Task 1 – Literature Review and State-of-Practice, other critical parameters affecting snow fence capacity are: fence porosity, length, and the presence of
a gap at the bottom of the structure. The effects of these parameters on the performance of the fences have been described in the Task 1 section of this report.

Although, several types of snow fences are available, as presented in Task 1 section of this report (Literature Review and State-of-Practice), the New Mexico Tech Research Team recommends the use of polymer fences with horizontal rails, approximately 50% porosity and a bottom gap of 15% of the fence height. While these structures usually have a higher initial cost than vertical wood fences, their installation is relatively simple and their maintenance cost is very low. If initial costs for these fences render their use prohibitive, wood fences with horizontal rails, approximately 50% porosity and a bottom gap of 15% of the fence height should be selected. Living fences are not recommended because of the large number of sites not conducive for tree planting in New Mexico, as well as the long period of time required for trees to mature and the fence to become fully functional. Finally, where results of the step-by-step design method presented in Task 6 (Match Analysis Methodology) determine that 4ft (1.2m) snow fences are sufficient for the location in question, vertical lath fences could be selected due to their relatively low cost and ease of installation.

COMPUTATIONAL FLUID DYNAMICS ANALYSES

To examine the performance of different snow barrier configurations, Dr. Andrew Budek-Schmeisser used FLOW-3D computational fluid dynamics (CFD) modeling software. It is important to stress that CFD modeling is only used as a research tool, and should not be used as a design tool. It provides insight on potential new configurations and allows for analyses of the effects changes in different fence parameters or in the wind speed will have on the system. However, these models could not be validated by field experiments due to the high costs of constructing and monitoring each configuration analyzed. In fact, only two configurations were constructed, an 8.5ft (2.6m) polymer fence at the Clines Corners location and a 12ft (3.7m) vertical wood fence with vertical slats at the Eagle Nest site. Even in these cases, the scarcity of snow in the two winters that followed the construction of the structures made it impossible for meaningful data to be collected for the validation of these models. Results of Dr. Budek-Schmeisser’s analyses and a summary of his observations are presented below. Because these analyses were only meant to provide researchers with a better understanding of the systems, and not as a design tool, Dr. Budek-Schmeisser decided to present only qualitative results.

The operating principle on which snow fences work is the dissipation of energy from the free stream airflow through the creation of a turbulent zone, immediately downwind from the fence. This removes enough energy from the airflow so that snowflakes can no longer be carried on the wind. CFD iterates fluid dynamic equations over small time steps to follow the path of discrete particles through a flow field. It allows for the determination of areas of higher and lower energy by modeling turbulent flow and pressure gradients. Because the performance of horizontal rail fences has been well documented in the literature, turbulent dissipation was initially modeled for a horizontal rail fence and used as a calibration model. In all simulations, air enters at an initial nominal velocity from the left vertical boundary. The right vertical boundary is outflow and the upper horizontal surface is maintained with stagnation pressure. A turbulent flow model using renormalized group analysis was used due to its robustness.
Horizontal slats of the snow fence were modeled as rigid elements with a width of 0.2m (0.7ft). In Figure 52, they are represented by the vertical dashed line on the left side of the figure. To obtain 50% porosity, gaps between slats were also set at 0.2m (0.7ft). This figure presents qualitative results of the analysis, that is, the presence of an area of energy dissipation or turbulent flow indicated by the red, orange, yellow, green and lighter blue colors. The lenticular shape of this turbulent area and its location correspond with field observations of drift formation downwind from the fence.

FIGURE 52 CFD Analysis of a Horizontal Rail Fence – Turbulent Energy Dissipation
Vertical Profile

The second analysis performed was that of a 4ft (1.2m) vertical lath fence with 50% porosity and no gap at the bottom. As shown in Figure 53, the energy dissipation profile of these structures is very different than that of the fence with horizontal slats. In fact, the area of energy dissipation downwind from the fence with vertical slats is a lot more elongated and extends further from the fence than that of the fence with horizontal rails and bottom gap, indicating that drifts downwind of these fences will probably be more elongated. It can also be noted that the area of energy dissipation begins in the upwind side of the fence and extends through the structure, indicating that snow may deposit close to the toe of the structure on either side of the fence, which agrees with field observations.

FIGURE 53 CFD Analysis of a 4ft (1.2m) Vertical Lath Fence with No Gap at the Bottom – Turbulent Energy Dissipation Vertical Profile
The same 4ft (1.2m) vertical lath fence with 50% porosity was then modeled with an 8in (20.3cm) gap at the base. Figure 54 shows the energy dissipation vertical profile of the system and clearly illustrates the effect of the bottom gap which allows air to flow under the fence, preventing snow deposition close to the toe of the structure, and assuring that it will not be buried or lose its efficiency.

![CFD Analysis of a 4ft (1.2m) Vertical Lath Fence with an 8in (20.3cm) Gap at the Base – Turbulent Energy Dissipation Vertical Profile](image)

Once the initial analyses were conducted and results obtained were found to correspond well with field observations, Dr. Budek-Schmeisser investigated different snow fence configurations for use in areas with restricted storage area. This is of particular concern because if all of the snow could be stored in the right-of-way, there would be no need to place snow barriers in private properties. Figure 55 presents the configuration Dr. Budek-Schmeisser considered the most promising for such sites. It consists of an 8ft (2.4m) composed structure: the bottom portion is a 4ft (1.2m) vertical lath fence, while the top portion of the fence is made of horizontal rails. The intent was to create a deep drift very close to the structure, hence providing a large storage capacity in a relatively small area. It seeks to improve the performance of 4ft (1.2m) lath fences which have been reported to function well until their burial. Once this happens, a somewhat leveled surface is created on either side of the system and the added horizontal rails should start creating a lenticular drift downwind of the fence, over the already stored snow. Results of CFD analysis of this system were promising. Figure 56 presents the analysis of the upper portion of the system, after the 4ft (1.2m) vertical lath fence is buried. As illustrated in this figure, the area of turbulent energy dissipation is lenticular and close to the fence, indicating that the system may function as predicted.
FIGURE 55 Snow Barrier System Proposed for Constricted Sites – Horizontal Rails above a 4ft (1.2m) Vertical Lath Fence

FIGURE 56 Turbulent Energy Dissipation Vertical Profile Obtained with Snow Barrier System Proposed for Constricted Sites – Horizontal Rails above a 4ft (1.2m) Vertical Lath Fence
TASK 5 – EFFECT OF LEVEL OF SERVICE AND COST/BENEFIT ANALYSIS

EFFECT OF LEVEL OF SERVICE

Intuitively, one can accept that the larger the volume of vehicles and the higher their speed, the larger the amount of drifted snow dissipated. Thus, increasing the number of vehicles on the road seems to enhance snow barrier performance. However, to accurately determine the effects of level of service on snow barrier performance, field experiments would have to be conducted. These would consist in the erection of snow fences on roadways with similar features, but different levels of service. In addition, for each level of service, there might be a limit in the volume of snow that can be displaced effectively by vehicles. To quantify the contribution of vehicles to snow removal from the roadway, for each site with a different level of service, fences should be constructed at different set back distances from the roadway, each allowing for a longer stretch of the drift to form on the pavement. However, such experiments are cost-prohibitive. Unfortunately, a search of the literature yielded no results. The author believes that even if the amount of snow dissipated by traffic could be quantified and related to a certain level of service, these values should not be used in design because levels of service usually vary significantly within a 24-hour period.

COST/BENEFIT ANALYSIS

As will be described in Task 7, two snow fences were constructed as part of this research project: one in the Eagle Nest region (November 2010) and one in the Clines Corners region (March 2011). At the time of the writing of this report, the fences have only been in place for a short period of time and maintenance has not yet been required. Therefore, it is not possible for maintenance or lifecycle costs to be obtained from the NMT research team’s experience with these structures. Unfortunately, savings resulting from a reduction in plowing needs could not be determined for these projects either. Not only did the winters of 2010-2011 and 2011-2012 not bring a significant amount of snowfall to these areas for an analysis to be made, the test structures were so short that it was not possible to quantify plowing costs for the small areas protected by the fences. For these reasons, a traditional cost-benefit analysis cannot be performed for these structures at this time.

Instead, information on initial costs, maintenance requirements, savings achieved by reducing plowing needs, and reduction in the number of accidents and road closures were obtained from the literature and from conversations with Kathy Alhenius from the Wyoming Department of Transportation.

Snow Fences Installation and Maintenance Costs

Snow barrier projects vary significantly in price based on material used and the type and the size of the fence selected. NMDOT personnel reported that the current estimated cost of existing 4ft (1.2m) fences is $5,000/mi ($3,107/km) for slats only, another $5,000/mi ($3,107/km) for barb
wire and posts and $5,000 to $10,000/mi ($3,107/km to $6,214/km) for labor. Costs listed in the literature vary greatly, sometimes even for the same type of structure. One document claims that the cost of the 32.2 mi (51.8 km) of fences installed in Wyoming was $1,900,000, yielding a cost of $11.10/ft ($36.42/m) (3). Another, also in 1979, states that the Wyoming Highway Department spent $313,719 in the construction of snow fences along 29.9 mi (48.1 km) of Interstate 80 between Laramie and Walcott Jet ($1.99/ft or $6.53/m) and $43,014 in 12.4 mi (20 km) on US 85 north of Cheyenne ($0.66/ft or $2.17/m) (14). Finally, the United States Department of Agriculture (USDA) Natural Resources Conservation Center (9) found that the average cost of living snow fences were estimated as $3/mi ($1.86/km) per year for each unit of snow trapped, while the cost of the 4 ft (1.2 m) slat fences were $185/mi ($115/km) per year.

Initial costs of permanent Wyoming wood barriers and portable HDPE barriers proposed by Tabler in a workshop in 1979 were comparable. However, the reduced manpower costs associated with the portable fences should be considered when selecting one of the alternatives (3). Costs of installing removable 4 ft (1.2 m) high snow fences were also presented by Baker (21) who compiled data from different regions of the Province of Ontario. The average installation and removal costs in Southwestern Ontario were recorded as $3.74/m ($1.14/ft), while prices in Eastern Ontario were twice as high: $8.00/m (2.44/ft), and in Northern Ontario, they reached $10.45/m ($3.19/ft). Prices reported did not include material costs and were obtained through phone interviews of ten road departments for the 1994-1995 winter.

Costs for each type of fence and maintenance expected or observed are summarized in Table 8. It is important to note that initial costs reported for the polymer fence were considered excessive by the manufacturer. According to Kathy Alhenius from Winter Research Services at the WYDOT, the contractor, not being familiar with the new product, placed a very conservative bid. Also noteworthy is the fact that several of the costs reported do not reflect costs added due to change orders, which according to Ms. Alhenius can be very high: she mentioned a snow fence replacement project in 2009 whose change orders nearly reached $1,000,000.

An interesting maintenance plan is currently being used by the WYDOT for the Wyoming barriers as well as the vertical wooden fences. In this case, the contractor replaces the face boards at their own expenses (labor, material and equipment) and is allowed to keep the harvested slats for furniture making. The WYDOT provides material for any other repair work necessary. Personnel from the Maintenance Department of the WYDOT are required to inspect each fence after the work is performed. This type of contract is only valid for repair of existing fences. Reconstruction and installation of new fences is performed separately and follow different provisions.

Snow Fences Benefits

One of the main objectives of installing snow fences is to reduce costs associated with snow removal. Of all road operations, snow removal is probably the one that places the most demands with respect to manpower and equipment, but also with respect to budget (3). During the harsh winter of 1978-79, Wyoming used all manpower and equipment available for snow removal and spent a total of $5.5 million on that operation alone (14). Similar situations were observed in
other countries. In Ontario, Canada, for example, an average of $3,000/km or $4,828/mi ($0.91/ft or $3/m) is spent yearly in snowplowing and sand/salt application (20).

Reports on the savings achieved due to the placement of snow fences varied tremendously in the literature. A summary of the main findings is presented in the following. Josiah and Majeski (25) reported that Tabler (26) evaluated 18 different sites in Minnesota where savings from snow removal alone on an average winter yielded benefit/cost ratios ranging from 9:1 to 46:1. Reductions of 50% in costs for snow removal have been observed by Hurlbut (1), while Tabler (15) reported that the WYDOT was able to reduce plowing costs by more than one-third on a 45-mile stretch of I-80. This is because in this report, plowing costs were estimated to be approximately 100 times higher than the cost of snow fence installation. In fact, costs of storing snow over the service life of the fence were reported as $0.03/ton, while costs of removing snow were calculated at $3.00/ton. An interesting study was conducted by Tabler and Furnish (27) who tracked snow and ice removal savings as different sections of Wyoming I-80 were being protected by snow fences. Because the study was conducted over several years, while new fences were being erected, expenditures were reported as the ratio of snow removal costs in the protected section over snow-removal costs in the remainder of the highway, a ratio independent of inflation. Results showed that snow fences reduced costs of snow and ice removal by at least a third. However, snow fences at these sites did not seem to affect the amount of time roads had to be closed because road closures can occur even if poor visibility is observed in only a small unprotected section of the highway. Therefore, Tabler and Furnish (27) believe that highways need to be completely protected by snow fences before reductions in road closure time are observed. In fact, a later publication on the performance of the snow fences in the same area (28) reported that 73% of the roadway was protected by snow fences and that this coverage lead to a reduction in road closure time by an average of 8 days per year. Crash rates were also assessed over the 34-year life of the structures and a decrease in the frequency of accidents was observed.

A cost-benefit analysis was presented in Tabler (29). However, expenses associated with snow and ice removal were not included in the analysis due to the author’s inability to quantify this benefit. Only benefits resulting from reductions in the number of crashes and the amount of road-closure time were considered. Costs included initial construction costs, an annual maintenance cost of 5% of the structure’s replacement cost, and the easement cost, which was estimated at $1.00/ft ($3.28/m). Results of the analysis yielded a benefit-to-cost ratio of 16.7:1.

Kathy Alhenius from the WYDOT estimated that in 2009 the WYDOT cost of maintaining wooden snow fences at $10,000/year and the cost of plowing the same length of roadway at $295,000/year.
TABLE 8 Initial and Maintenance Costs for Different Types of Snow Fences. To Allow for Comparison, Costs Reported Were Converted to Present Value (October 2011) Using Historical Cost Indices Provided by RS Means. Conversion: 1ft = 0.3m.

<table>
<thead>
<tr>
<th>Snow Fence Type</th>
<th>Height (ft)</th>
<th>Initial Cost/ft ($)</th>
<th>Service Life (years)</th>
<th>Maintenance</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wyoming fences</td>
<td>6</td>
<td>29.08</td>
<td></td>
<td></td>
<td>(27)</td>
</tr>
<tr>
<td>(wood)</td>
<td>8</td>
<td>35.65</td>
<td></td>
<td></td>
<td>(27)</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>17.92</td>
<td>25</td>
<td>Maintenance costs are estimated at $6428.40/mi/year.</td>
<td>(31)</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>41.54</td>
<td></td>
<td></td>
<td>(27)</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>53.48</td>
<td></td>
<td></td>
<td>(27)</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>19.35*</td>
<td>20-25</td>
<td>Maintenance costs are estimated at 5% of the initial cost.</td>
<td>(30)</td>
</tr>
<tr>
<td></td>
<td>6 - 14</td>
<td></td>
<td></td>
<td>Annual maintenance costs are estimated at 5% of the initial cost.</td>
<td>(28)</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>18.90**</td>
<td></td>
<td>Very labor intensive and required on an yearly. Example: 3 months were required for a crew of 3 to 4 men to check anchors, tighten bolts and repair fences on a 13-mi stretch of roadway.</td>
<td>Alhenius, pers. com.</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>29.99**</td>
<td></td>
<td></td>
<td>(28)</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>28.84**</td>
<td></td>
<td></td>
<td>(28)</td>
</tr>
<tr>
<td>Vertical wood</td>
<td>10</td>
<td>29.38**</td>
<td></td>
<td>Annual maintenance is required and includes checking of the anchors, tightening of the bolts, and repairs in general.</td>
<td>Alhenius, pers. com.</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>46.05**</td>
<td></td>
<td>Maintenance costs in a 40-mi road stretch in the state of Washington are estimated at $5,000/mi/year.</td>
<td>Alhenius, pers. com.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15.87</td>
<td></td>
<td></td>
<td>(32)</td>
</tr>
<tr>
<td>Polymer</td>
<td></td>
<td>60.49**</td>
<td></td>
<td>Require very little maintenance. These structures have been in place for 3 years and so far only tightening of the straps have been necessary. Tightening of the bolts is anticipated in the future.</td>
<td>Alhenius, pers. com.</td>
</tr>
<tr>
<td>Vertical lath fences</td>
<td>4</td>
<td>2.01**</td>
<td></td>
<td></td>
<td>Alhenius, pers. com.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 – 7</td>
<td></td>
<td></td>
<td>(9)</td>
</tr>
<tr>
<td>Living</td>
<td>3 rows</td>
<td>4.36*</td>
<td>50-75</td>
<td>Maintenance costs are estimated at $1029.60/mi/year.</td>
<td>(31)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Maintenance costs are expected to be very low and consist of only weed control and replanting during the first few years.</td>
<td>(32)</td>
</tr>
</tbody>
</table>

* Year in which cost was incurred is not known
** Bid price – does not include additional costs due to change orders
As part of Task 6 – Match Analysis Methodology, a Field Guide was developed to provide NMDOT maintenance crew a practical guide for the design of snow barriers. It provides crews a brief introduction to snow fences and the principles of their operation. In addition, it describes the factors affecting snow barriers’ performance and takes a step-by-step approach to the design and placement of these structures. Finally, it describes the effects of snow fences on wildlife, the required steps to acquire land, and the surveys required before construction.

For completeness of this report, the design sections of the Field Guide are reproduced below. Because of the successful results of the work conducted for over 40 years by Dr. Ron Tabler in Wyoming, the design procedure recommended in the Field Guide relies extensively on the papers and reports he published and especially on the “Snow Fence Guide” he prepared in 1991 for the Strategic Highway Research Program, National Research Council (15).

The design process is broken down into four main steps (Figure 57): site identification, data acquisition, fence capacity, and ideal location and orientation. Each step will be addressed in detail in the sections below.

**FIGURE 57 Main Steps in the Design of a Snow Fence**

**SITE IDENTIFICATION**

Snow fences are designed to retain blown snow by causing deposition short distances downwind from their bases and forming snow drifts at these locations. Therefore, if properly designed and placed, they can be used in the protection or road sections. The identification of problematic sites that may be improved by the placement of snow fences often simply begins with the recurring observation of snowdrifts in a particular section of a road. Poor visibility and/or loss of traction are also good indicators that a problem exists and may be addressed by the placement of snow fences. Also of interest are areas where existing snow fences are being buried by snow because when this happens, the fences cease to be functional.

Although snow fences can generally be used to solve the problems listed above, they are not always the only or the most effective solution. Therefore, alternative solutions may also be considered. For example, Figures 58 to 62, from a very practical guide to common problems related to snowdrifts prepared for Transport Canada (20), show that drifts created due to the accumulation of snow in the upwind cut region of a roadway cross section can be reduced by the addition of snow fences (living or structural) or by changes to the embankment.
Recommendations on modifications to terrain profile to reduce or relocate snow drifts and can be found in Tabler (13, 16).

FIGURE 58 Snow Accumulation in Upwind Cut Region of a Roadway Section, Creating a Drift on the Roadway (20)

FIGURE 59 First Possible Solution: Regrading of Backslope to 7:1 or Less to Prevent Snow Accumulation in the Upwind Cut Region (20)

FIGURE 60 Second Possible Solution: Creation of Terraces to Provide Snow Storage Upwind from the Roadway (20)

FIGURE 61 Third Possible Solution: Installation of Snow Fences to Increase Storage Capacity of the System Upwind from the Roadway (20)
Once the site has been identified as a prospective candidate for the placement of snow fences, weather data and a field examination should be conducted to determine the feasibility of this plan and the potential effectiveness of these structures.

DATA ACQUISITION

Meteorological Data

Ideally, historical weather data for the site in question should be collected. It should include prevailing wind direction, wind speed, and snowfall. If such data is not available, at a minimum, prevailing wind direction should be determined on site because it is essential to the proper placement of the snow fence. The improper placement of snow fences can lead to the formation of drifts in unexpected directions and the creation of unnecessary problems.

If prevailing wind direction is to be determined on site, a portable weather station can be used to gather such information, but when not available, wind direction can be determined on site by observing the orientation of snowdrifts. Since weather systems may cause temporary wind shifts, to determine the most common drift orientation, several observations should be made throughout the winter.

Topographical Data

The topography of the surrounding area is also essential to the design of effective snow fences. Terrain profile upwind from the fence will determine the amount of snow that needs to be stored. Also affecting the capacity of the fence is the ground cover and the presence of obstacles such as fences, structures, ditches, etc. Therefore, the first step in this section is to determine the fetch, that is, the length of the open area adjacent to the roadway, from which snow will be picked up and transported to the site. It can be measured on site or on aerial photographs as the distance from the roadway to the nearest physical boundary. Examples of boundaries are: rows of trees, ditches, valleys, large buildings, rows of structures, stream channels, open water, etc (15, 20). Tabler (15) recommends an upper limit of 4mi (6.44m) for the fetch because most of the snow evaporates before traveling such distance.
REQUIRED FENCE CAPACITY

To determine the required fence capacity, one must first estimate the amount of relocated precipitation, that is, the amount of snow (in water equivalent) that is expected to be transported by the wind and reach the snow fence. Because a portion of the snow will melt or harden, not all precipitation will be transported by the wind and reach the fence (13). The relocated precipitation is estimated by subtracting the portion of the snow that is lost to evaporation from the total precipitation (Figure 63). Several factors affect evaporation rate: air temperature, humidity, atmospheric pressure, solar radiation, wind speed, among others. Estimating the annual volume of snow lost to evaporation is therefore a challenging task. For practical purposes, the following recommendations are made based on experimental work: (1) total precipitation in water-equivalent can be approximated by 10% of the average annual snowfall and (2) relocated precipitation can be conservatively assumed to be 70% of that value (15).

FIGURE 63 Illustration of the Concept of Snow Transport (15).

Once the fetch and the relocated precipitation have been determined, Figure 64 can be used to obtain the total seasonal snow transport. If this value is considered to be the required storage capacity of the fence, that is, if it is assumed that snow stored by the fence will not melt throughout the winter, Figure 65 can be used to determine the required fence height. Although multiple rows of shorter snow fences could also provide the required storage capacity, because the relationship between fence height and storage capacity is nonlinear, a very large number of rows may be required in most instances. For example, 5 rows of 4ft (1.22m) fence are required to provide the same storage capacity as 1 row of 8ft (2.44m) fence. Additional advantages of taller fences are improved driver visibility, less land requirements, and reduced costs (15).

Although several types of snow fence are available, the New Mexico Tech Research Team recommends the use of polymer fences with horizontal rails, approximately 50% porosity and a bottom gap of 15% of the height of the fence. While these structures have shown to have a higher initial cost, their installation is relatively simple and their maintenance cost is very low. If initial costs for these fences render their use prohibitive, wood fences should be selected. Living fences are not recommended because of the large number of sites in New Mexico not conducive for tree planting, as well as the long period of time required for trees to mature and the fence to become fully functional.
FIGURE 64 Total Seasonal Snow Transport as a Function of Fetch and Relocated Precipitation (15)

FIGURE 65 Relationship between Fence Height and Snow Storage Capacity (15)
SNOW FENCE LOCATION AND ORIENTATION

Ideally, snow fences should be placed perpendicular to the prevailing wind direction. However, little change in capacity was observed with angles of attack ranging between 55° and 90° (13), where the angle of attack is defined as the angle the prevailing wind direction makes with the road. Therefore, for these cases, the fence should be placed parallel to road, as shown in Figure 66. To account for wind direction fluctuations, snow fences should extend beyond the area to be protected. Tabler (16) recommends that they be designed to intercept winds that deviate 30° from the prevailing wind direction, as illustrated in Figure 66. Fences with 50% porosity on flat terrain should be placed a distance equal to at least 35 times the height of the fence from the edge of the road. Because this distance corresponds to the expected length of the drift when fence capacity is reached, it should be measured along the prevailing wind direction instead of perpendicular to the road. However, if wind direction is expected to fluctuate, the worst case scenario should be considered, which, in the set-up presented in Figure 66 would be to measure the setback distance perpendicular to the road. For fences of different porosity, the following equation can be used to determine the minimum setback distance (16):

\[ D_{\text{min}} = (\sin \alpha)(12 + 49P + 7P^2 - 37P^3)H \]  

(2)

where \( D_{\text{min}} \) is the minimum setback distance, \( \alpha \) is the attack angle, \( P \) is the fence porosity, and \( H \) is the fence height. Because required setback distance may not always be available, denser fences, that is, fences with porosity lower than the recommended 50% may be selected. However, with the reduction in drift length shown in Figure 16 also comes a reduced storage capacity, and hence a less effective system.

For angles of attack smaller than 55°, oblique fences are recommended. In these cases, multiple rows of fences are usually necessary to protect the entire area of interest (Figure 67). To assure proper coverage of the road section, Tabler (33, cited in 16) recommends not only that fences overlap by a distance of 15 times the fence height, but that a fence parallel to the road be used in conjunction with the oblique fences to capture the near snow. The minimum suggested distance between different rows is 25 times the height of the fence to provide enough room between fences for the drifts to form and to prevent downwind fences from becoming buried (Figure 67). Although the setback distance from the road could be measured parallel to the wind direction, Figure 67 shows a more conservative approach where the setback distance is measured perpendicular to the road and is equal to 35 times the height of the fence for fences with 50% porosity. If a fence of a different porosity is selected, Equation 2 can be used to determine the minimum setback distance. Finally, to ensure full coverage of the section of interest, oblique fences should also be designed to intercept winds that deviate 30° from the prevailing wind direction, as illustrated in Figure 67.
FIGURE 66 Angle of Attack and Recommended Fence Extension Beyond Road Section to be Protected (Adapted from illustrations in 16)

FIGURE 67 Placement of Oblique Snow Fences Recommended for Attack Angles Smaller than 55° (Adapted from illustrations in 15 and 16)
Topography also has a serious effect on drift shape and size. The estimated length (35 times the height of the fence) and height (1.0 to 1.2 times the height of the fence) of the drifts recommended above are valid for fences placed on level terrains, that is, where the slope is less than 15°. Fences placed on a ridge or in areas upwind of a depression will provide additional storage because their drifts will not only be higher, but also more elongated (Figure 68). Drifts of fences placed on sloping terrain will also have their shape and size affected by the terrain. According to Tabler (13), for downward slopes (steeper than 15%), more snow will accumulate on the upwind side of the fence drifts, leading to burial of the fence. The drift on the downwind side of the fence will be elongated, as shown in Figure 68. For fences placed on upward slopes greater than 15% will cause the formation of shorter and shallower drift on the upwind side of the fence and little or no snow accumulation on the downwind side of the fence.

FIGURE 68 Influence of Topography on the Shapes of Drifts (17 cited in 13, 16)

EFFECT OF SNOW FENCE ON LIVESTOCK AND WILDLIFE

To allow for the passage of wildlife, the Wyoming Department of Transportation provides openings in the snow fences every 660ft (201m) (Kathy Ahlenius, personal communication). However, Ronald Tabler has shown his disapproval for such practice due to the reduced effectiveness of the fences at these locations (13, 15), as illustrated in Figure 69. To accommodate landowners and wildlife officials’ requests for openings to allow the passage of
livestock or wildlife, three configurations were proposed in Tabler (13) and are presented in Figure 70. The first type of opening (Type A), which is also the preferred type, consists in overlapping two lines of fences. While it provides continuous coverage along the entire length of the roadway, the opening does not allow for vehicular traffic during the winter months. If the opening through the fence must be kept free of snow to allow the passage of vehicles year round, Tabler (13) presents two solutions: Types B and C in Figure 70. Type B only offers off-road access through the narrow openings (16ft or 5m) that are left between snow fence panels. Because the opening is quite narrow, the wind passing through it will accelerate and scour a path through the drift. Type C is recommended for roads that intersect the snow fence and must be kept open year-round. For these locations, the snow fence should be set a distance of 5H (where H is the height of the fence) from either side of the shoulders of the intersecting road.

![Picture of gaps created by cattle and their effect on the drift](image)

**FIGURE 69 Gaps Created by Cattle and Their Effect on the Drift**

In New Mexico, landowners and ranchers have contacted NMDOT personnel and expressed their need for periodic access through snow fences with 4 wheelers or pickup trucks. For this reason, the Department of Transportation has been using Type A access configuration (Figure 20) with a width of 10 to 12ft (3 to 3.7m) and 12ft (3.7m) overlap. Each fence section has been no longer than 1320ft (402.3m), and to accommodate the overlap, they have been angled so that the distance from the fence to the pavement is 12ft (3.7m) further at the end of the fence than at the beginning of the structure. Since this procedure has accommodated landowners’ needs while keeping the fences functioning without interruption, it should be continued as new fences are designed and installed. However, if vehicular access must be ensured throughout the winter, Type A configuration cannot guarantee that the overlapping region will be kept entirely free of snow, especially if fences 8ft (2.4m) or taller are used. In these cases, it is advisable to place openings as far apart as possible and use configuration Type B, even though it will create an unprotected section on the roadway.

Unfortunately, no studies have been found on the effects of structural snow fences on wildlife behavior or migration patterns. However, numerous publications on living snow fences stress
the fact that they are very beneficial to wildlife, creating habitat for birds, mammals, and even deer (9, 11, 25, 34); improving pollination (35); providing food and water for pheasants, partridges, deer, and songbirds as well as protecting wildlife and livestock during winter storms (15, 25, 32, 35, 36, 37, 38), hence increasing population sizes and promoting biodiversity. In fact, Schroeder (32) highlights a study performed by the University of Wyoming that showed that cattle protected from the wind during harsh winter months required less feed and maintenance than animals left unsheltered. These findings are of great interest to cattlemen who usually have to increase the amount of feed during cold and windy winters to keep their animals healthy (30, 32).

In addition, the Environmental Management Section of the Canadian Ministry of Transportation and Highways (39) published an interesting document on how the placement of wildlife exclusion fences (also known as deer fences) 8ft (2.4m) high on both sides of a road lead to a 97 to 99% reduction in the number of accidents involving vehicles and animals. In fact, this document discusses a study on a 22mi (35km) section of the Coquihalla Freeway between Hope and Merritt in British Columbia that compared the number of accidents that occurred in the 4 years before and the 4 years after the installation of the exclusion fences. At that particular location, 100% reduction in accidents involving wildlife was observed. Similar results were
observed at the Banff National Park in Alberta, Canada, where Clevenger and colleagues (40) assessed the effectiveness of highway mitigation fences at reducing wildlife-vehicle collisions. Their main concerns involved not only the safety problems for drivers, but also the high mortality rate of wildlife, mainly due to the fact that some species were being significantly affected. For this reason, fences were installed along 16mi (26km) of the Trans-Canada Highway through the Banff National Park. Underpasses were provided at different locations for wildlife crossing. Results of this study indicated that the fences reduced the number of accidents involving wildlife by 80%. It was also noted that the number of such accidents were 4 times higher on unfenced areas than on fenced sections of the road; however, it is important to note that mortality rates were not compared to population levels. Also of interest is the fact that clusters of wildlife-vehicle accidents were observed at the end of the fences and that this observation has also been made by other researchers cited by the authors. Finally, the authors noted that although the fences were effective in preventing ungulates (deer, elk, moose, etc) from reaching the road, wolves and coyotes were able to crawl under the fence at different locations and access the right-of-way, while black bears, grizzly bears, and cougars climbed them with a certain ease. In addition to the fences, Clevenger et al. (40) recommended that V-shaped fence ends be provided to guide wildlife following the fence to passages created at these locations. In addition, the authors suggested the use of infrared beams to trigger alarms when wildlife approach the right-of-way, as used in Finland and reported in Taskula (41).

More recently, the Colorado Division of Wildlife Officers and the Colorado State Patrol reported that 8ft (2.4m) fences installed on a 4mi (6.4km) stretch of Highway 82 near Aspen, Colorado considerably reduced animal-vehicle collisions (42). Escape ramps that only allow access from the roadway to the shoulders but not the other way around were also provided to prevent animals from been trapped in the roadway. Wildlife officer John Groves and wildlife manager Perry Will do not believe that the fences are adversely affecting deer and elk in the area. John Groves even mentions that these animals do not need access to open water because they can obtain it from snow and aliments.

Therefore, even though no studies analyzing the effects of snow fences on wildlife were found, because, like the wildlife exclusion fences, 8ft (2.4m) or higher snow fences will prevent the passage of larger animals, similar conclusions can be drawn. In fact, reports show that even though deer are capable of jumping as high as 15ft (4.6m), they do not usually do so unless threatened (43, 44). For this reason, the most commonly used height for exclusion fences is 6 to 7ft (1.8 to 2.1m), although barriers as high as 15ft (4.6m) are also available (43, 44, 45). For this reason, the research team believes that the placement of 8ft (2.4m) or higher snow fences along the study sections will probably lead to a reduction in accidents involving elk or deer. However, there is a chance that these types of accidents become clustered at the ends of the fences. If that is the case, the construction of wildlife underpasses or the installation of animal-triggered alarms may be necessary at these locations. It is also important to note that the gap at the bottom of the fence may allow the passage of some species of deer. Falk et al. (46), Palmer et al. (47), and Feldhamer et al. (48) cited in VerCauteren et al. (49) reported that adult white-tailed deer were able to crawl through gaps of 10in (25cm), while Ward (50), also cited in VerCauteren et al. (49), found that mule deer manage to pass through gaps of only 6in (15cm). Since Tabler (15) recommends a bottom gap of 10 to 12% the height of the snow fence, measured from the top of the existing vegetation or the anticipated snow cover, an 8ft (2.4m) fence would require a gap of
9.6 to 11.5in (24 to 29cm), which, according to the studies mentioned above, could allow the passage of certain deer species.

While environmental impact analyses would be necessary to clearly define the impacts of the snow fences on the animals inhabiting each of the sites, general preliminary conclusions can be drawn based on the studies cited above: (1) larger animals such as elk, and deer will probably not be seriously affected by the fences since, according to wildlife officer John Grove (42), they do not need access to open water, (2) smaller animals such as coyotes and foxes will probably not be affected either since they will be able to pass under the fences. However, if providing wildlife with open water access is desired, snow fences strategically placed may also be used to improve or even create water supplies (30).

To determine the effects of the snow fences on migration patterns of larger animals inhabiting the two study sites, environmental impact analyses would be necessary. In fact, researchers have reported that exclusion fences can hinder, not only migration of such animals, but also their daily movements (51, 52 cited in 49).
**TASK 7 – CONSTRUCTION OF SNOW BARRIERS FOR EVALUATION**

Two snow fences were constructed for evaluation at the locations selected by the Technical Panel: one in the Clines Corners region and one in the Eagle Nest region. These sites were selected based on their history of snowdrift formation on the roadway. They were visited by the New Mexico Tech research team in the Summer of 2009 for evaluation of topographical parameters and in the Winter of 2010 for understanding of site conditions under wintery conditions. Results of these field visits were reported under Task 2 of this report. Although a third site was also visited at these occasions (Black Lake), financial limitations prevented the construction of a third snow fence.

Once the two sites were selected and evaluated, the Match Analysis presented in Task 6 of this report and in the Field Guide developed as part of this research project was used to design two snow barriers for field evaluation. This process is described below.

**SNOW FENCE DESIGNED FOR CLINES CORNERS SITE**

**Site Identification**

The site selected in the Clines Corners region is located on US 285, less than a mile south of the I-40 intersection, as indicated on Figure 71. It was selected as a test site for this project due to the recurring problems with snow drifts on the road observed by NMDOT personnel.

![Figure 71 Clines Corners Test Site](image)
Data Acquisition

Meteorological Data

Because weather conditions are essential in determining snow fence dimensions and placement, they should be as specific to the site as possible; the presence of microclimates caused by changes in the terrain and in land use may significantly affect snow transport, deposition, and accumulation. Historical weather data for the region of Clines Corners was obtained from three different sources. Data presented in Table 9 was obtained from World Climate (24) and represents the average temperatures and monthly precipitation over the following years: 1971 to 2000. Average wind speeds are shown in Table 10 and are based on data collected by the Western Regional Climate Center of the Desert Research Institute, Nevada System of Higher Education (53) from 1996 to 2006.

TABLE 9 Average Temperature and Monthly Precipitation for the Clines Corners Region (24) Conversion: 1in = 2.54cm; °F = 1.8 °C + 32.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Temperature (°F)</td>
<td>18.1</td>
<td>20.5</td>
<td>24.5</td>
<td>29.8</td>
<td>39.6</td>
<td>48.5</td>
<td>53.9</td>
<td>53.1</td>
<td>45.6</td>
<td>35.3</td>
<td>24.6</td>
<td>18.6</td>
<td>34.34</td>
</tr>
<tr>
<td>Maximum Temperature (°F)</td>
<td>42.6</td>
<td>47.4</td>
<td>53.6</td>
<td>61.3</td>
<td>71.4</td>
<td>81.4</td>
<td>83.4</td>
<td>80.8</td>
<td>74.8</td>
<td>65.3</td>
<td>52.2</td>
<td>44.0</td>
<td>63.18</td>
</tr>
<tr>
<td>Monthly Precipitation (in)</td>
<td>0.95</td>
<td>0.81</td>
<td>0.99</td>
<td>1.03</td>
<td>1.62</td>
<td>1.64</td>
<td>2.77</td>
<td>3.14</td>
<td>2.22</td>
<td>1.45</td>
<td>1.09</td>
<td>0.96</td>
<td>1.56</td>
</tr>
</tbody>
</table>

TABLE 10 Average Wind Speeds for the Clines Corners Region. Data Presented in mi/h. (53) Conversion: 1mi/h = 1.61km/h

<table>
<thead>
<tr>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual Average</th>
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<tbody>
<tr>
<td>16.2</td>
<td>16.1</td>
<td>15.7</td>
<td>16.9</td>
<td>14.6</td>
<td>13.5</td>
<td>10.6</td>
<td>10.1</td>
<td>11.8</td>
<td>13.3</td>
<td>15.0</td>
<td>16.0</td>
<td>14.1</td>
</tr>
</tbody>
</table>

The most comprehensive data set was obtained from MesoWest (22), which is a partnership between researchers from the Atmospheric Sciences Department of the University of Utah, and forecasters from the Salt Lake City National Weather Service Office, the National Weather Service Western Region Headquarters, as well as from other agencies, commercial firms and universities. Records obtained for the Clines Corners region only range from 2007 to 2010, but include maximum and minimum temperatures, relative humidity, total precipitation (rain and/or melted snow), wind speed, wind direction, and wind gusts, all measured several times a day. A summary of the data is presented in Table 11. This data was also used to create histograms for wind speed (Figures 72 and 73) and wind direction (Figure 74), so that prevailing conditions could be observed. From these figures, it can be concluded that predominant winds are around
10 to 12mi/h (16.09 to 19.31km/h), that the 85th percentile is approximately 20mi/h (32.19km/h), while the 95th percentile is approximately 27mi/h (43.45km/h). With respect to wind direction, it can be seen that winds of approximately 300°, that is, northwest winds, predominate. In addition, it is important to note that east winds of approximately 87 to 90° also occur frequently.

### TABLE 11 Summary of Historical Data from MesoWest for Clines Corners Region. (22)

<table>
<thead>
<tr>
<th>Month/Year</th>
<th>Total precipitation (in of liquid equivalent)</th>
<th>Average temperature (°F)</th>
<th>Average high temperature (°F)</th>
<th>Average low temperature (°F)</th>
<th>Average wind speed (mi/h)</th>
<th>Maximum wind speed (mi/h)</th>
<th>Maximum gust (mi/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/2007</td>
<td>11.94</td>
<td>22.22</td>
<td>39.02</td>
<td>-2.92</td>
<td>14.41</td>
<td>42.58</td>
<td>49.48</td>
</tr>
<tr>
<td>02/2007</td>
<td>0.34</td>
<td>28.05</td>
<td>53.96</td>
<td>1.94</td>
<td>19.00</td>
<td>46.03</td>
<td>58.69</td>
</tr>
<tr>
<td>03/2007</td>
<td>0.48</td>
<td>42.23</td>
<td>73.04</td>
<td>6.08</td>
<td>13.21</td>
<td>35.67</td>
<td>50.64</td>
</tr>
<tr>
<td>04/2007</td>
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<td>43.75</td>
<td>73.94</td>
<td>19.40</td>
<td>14.91</td>
<td>43.73</td>
<td>54.09</td>
</tr>
<tr>
<td>05/2007</td>
<td>3.01</td>
<td>53.56</td>
<td>77.00</td>
<td>30.92</td>
<td>11.72</td>
<td>32.22</td>
<td>51.79</td>
</tr>
<tr>
<td>06/2007</td>
<td>0.24</td>
<td>58.81</td>
<td>91.04</td>
<td>30.92</td>
<td>11.52</td>
<td>43.73</td>
<td>55.24</td>
</tr>
<tr>
<td>07/2007</td>
<td>0.81</td>
<td>69.12</td>
<td>89.96</td>
<td>53.06</td>
<td>8.87</td>
<td>27.62</td>
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</tr>
<tr>
<td>08/2007</td>
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<td>69.76</td>
<td>91.94</td>
<td>53.06</td>
<td>10.16</td>
<td>31.07</td>
<td>47.18</td>
</tr>
<tr>
<td>09/2007</td>
<td>1.06</td>
<td>62.14</td>
<td>82.94</td>
<td>44.06</td>
<td>10.82</td>
<td>33.37</td>
<td>42.58</td>
</tr>
<tr>
<td>10/2007</td>
<td>0.21</td>
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<td>77.00</td>
<td>24.08</td>
<td>14.36</td>
<td>36.83</td>
<td>51.79</td>
</tr>
<tr>
<td>11/2007</td>
<td>0.31</td>
<td>39.31</td>
<td>69.08</td>
<td>10.04</td>
<td>12.54</td>
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FIGURE 72 Histograms Showing Frequency and Cumulative Frequency of Wind Speed in the Clines Corners Region from 2007 to 2009. (1mi/h = 1.61km/h).
FIGURE 73 Histograms Showing Frequency and Cumulative Frequency of Wind Speed in the Clines Corners Region from January 2010 to March 2010. (1mi/h = 1.61km/h).

FIGURE 74 Histograms Showing Frequency and Cumulative Frequency of Wind Direction in the Clines Corners Region from 2007 to 2010. (1mi/h = 1.61km/h).
Topographical Data

The land in the study area was observed to be gently rolling, with very low vegetation, consisting mainly of grass on both sides of the road. The existing snow fences were made of vertical wood slats and were approximately 4ft (1.22m) tall. They had no gap at the bottom and a porosity of approximately 60%. The distance from the fences to the edge of the pavement was approximately 56ft (17.07m). As mentioned previously, short fences tend to behave a little differently than their taller counterpart, becoming partially buried before the drift behind them ceases to grow (13). Nonetheless, a distance of approximately 35 times the height of the fence is in general desired for storage of a downwind drift. Therefore, the fences were found to be too close to the road, not providing enough storage area for optimal performance.

Required Fence Capacity

Snow transport should first be estimated based on the size of the fetch. Aerial photograph of the site considered was used to determine the length of the fetch. Figure 7 depicts the fetch measured along the prevailing wind direction, which in this area is at most 16000ft (4877m).

The next step requires the determination of the relocated precipitation, which is generally taken as 70% of the precipitation (in water-equivalent) over the entire season, a value considered conservative for design purposes. Considering average temperatures as well as average high and average low temperatures for the Clines Corners region, it was assumed that all precipitation from November to March was snow, giving a total of 4.15in (10.5cm) of water-equivalent precipitation for the season. Therefore, the relocated precipitation for this area was initially determined as 2.91in (7.4cm). However, this value was considered to be too conservative because temperatures at Clines Corners during the winter months usually allow for the melting of some or all of the snow that accumulates in the region. A total precipitation of 2in (5cm) of water-equivalent, corresponding to roughly the total precipitation in two consecutive winter months, was deemed more reasonable. Therefore, the resulting relocated precipitation was estimated at 1.4in (3.6cm).

Seasonal snow transport is then determined based on the relocated precipitation and the length of the fetch (Figure 64). For Clines Corners, if no snow were to melt between November and March, the relocated precipitation would be 2.91in (7.4cm) and with a fetch of approximately16000ft (4877m), the seasonal snow transport would be approximately 35ton/ft (104t/m). However, as mentioned previously, a relocated precipitation of 1.4 in (3.6cm) was considered to be a more realistic value. With fetches of no more than 16000ft (4877m), the seasonal snow transport would be approximately 18tons/ft (54t/m).

The required fence height is determined using Figure 65 and the amount of snow transport determined previously. For the study site, if no snowmelt is assumed between November and March (seasonal snow transport of 35ton/ft or 104t/m), a 10ft (3m) snow fence would be necessary. However, if snow is assumed to melt throughout the winter, an 8ft (2.4m) fence would be sufficient for that site.
Snow Fence Location and Orientation

Because the prevailing wind for this study site was determined to be 300° (northwest winds), the angle of attack is 60°. Therefore, the fence should be placed parallel to the road. The setback distance should be 30 to 35 times the height of the fence (preferably 35), that is, 240-280ft (73.2-85.3m) if the 8ft (2.4m) fence is selected or 300-350ft (91.4-106.7m) for the 10ft (3m) fence.

CONSTRUCTION OF SNOW FENCE AT THE CLINES CORNERS TEST SITE

Construction of the structure was overseen by Dr. Andrew Budek-Schmeisser, while administrative issues related to this task were assigned to Mrs. Barbara Budek-Schmeisser. A summary of the construction process is presented in the following.

The New Mexico Tech Research Team decided to use an 8.5ft (2.6m) tall polyethylene fence for the Clines Corners test site because of the reported performance of these structures and their low maintenance costs. Budget available for this fence limited its length to 300ft (91.4m). This is a prefabricated fence supplied by Perma-Rail International, Inc.
As mentioned in the Task 2 section of this document, in Clines Corners, the land adjacent to the site of interest is owned by the state of New Mexico and leased for grazing. For this reason, the lessee was contacted regarding the placement of a snow fence in this area and agreed to grant NMDOT a temporary construction easement as well as a permanent easement for the snow fences. As shown in Figure 76, the permanent easement for the fences is 660ft (201m) long in the North-South direction with a width of 30ft (9m). Although the permanent easement was intended to be located 200ft (61m) from the edge of the right-of-way, after construction was terminated, measurements indicated that it was actually set by the surveyor at an average of 189ft (57.6m) from the right-of-way fence. An access road 15ft (4.6m) wide leading to the snow fences was also requested, as shown in Figure 76. The temporary construction easement is 100ft (30.5m) by 100ft (30.5m), and is located immediately west of the fence easement. This temporary easement was requested to allow for the storage of construction material storage as well as the maneuvering of vehicles. Once agreements were made regarding the easements and final design details were determined, the project was sent out for bids. The work was awarded to L&J Construction, Inc., Post Office Box 1943, Anthony, NM 88021.

FIGURE 76 Clines Corners Test Site Layout Including Easements and Snow Fence Details (Not to Scale) Conversion: 1ft = 0.30m; 1in=2.54cm

A Utility Survey was conducted to determine the presence of buried utility lines in the area (design-locate survey). It is important to note that this survey is only valid for 10 days and that 3 or 4 days prior to construction, the contractor still needed to order a second survey (standard-
locate survey) to assure that excavation could be conducted as planned and that the fence would not be built across buried utility lines, nor interfere with utility access. Archeological and Biological Surveys were also conducted prior to construction.

Installation of the snow fence occurred from March 28 to 30, 2011. Manufacturer’s guidelines were used and posts were bolted to anchors embedded in 4ft (1.2m) of concrete (Figures 77 and 78). Posts were set 10ft (3m) apart for a total length of 300ft (91.4m). Cables attached to end posts were also anchored to the ground approximately 16.5ft (5m) from the end of the fence at a depth of 8ft (2.4m) (Figure 79).

Polyethylene rails were placed on the last day of construction, after the concrete poured around the anchors was allowed to set for approximately 24 hours (Figure 80). Rails were secured to the intermediate posts with the use of guide handles, as shown in Figure 80 and to the end posts by a secured attachment at one end (Figure 81a) and a ratchet at the other end (Figure 81b). Coated wire stays are used 5ft (1.5m) from each post to minimize the movement of the rails between the posts (Figure 82). Figure 83 shows the finished fence. Although the contractor was not experienced in the installation of the snow fence selected, the work was completed in 3 days with only two workers. Material costs totaled $10,566 while labor was $10,083, for a total of $20,649. Due to the repetitive nature of the work, it is the author’s belief that the construction process could be significantly faster, as workers become familiar with the required procedures.
FIGURE 78 Detail of Polyethylene Fence Posts’ Anchoring System

FIGURE 79 Detail of Cable Anchoring System on Either End of Polyethylene Fence
FIGURE 80 Placement of the Horizontal Polyethylene Rails

(a) Secured Connection  (b) Ratchet

FIGURE 81 Rail Attachments to End Posts
FIGURE 82 Coated Wire-Stays to Minimize Movement of Rails between Posts

FIGURE 83 Polyethylene Snow Fence Built at the Clines Corners Test Site
SNOW FENCE DESIGNED FOR EAGLE NEST SITE

Site Identification

In the Eagle Nest area, the test site selected is situated on US 64, immediately across from the Mountain View Cabins which are located at 28386 Hwy 64, Eagle Nest, NM (Figure 84). It was selected by members of the Technical Panel due to the extensive plowing requirements in the area. In fact, as described in Task 2 of this project, NMDOT has to repeatedly create snow walls in the right-of-way in this area to increase the capacity of the existing 4ft (1.2m) snow fences.

FIGURE 84 Eagle Nest Test Site

Data Acquisition

Meteorological Data

Meteorological data for the Eagle Nest area was obtained from the Western Regional Climate Center of the Desert Research Institute, Nevada System of Higher Education website (53). Monthly average temperatures and precipitation are presented in Table 12 and are based on data collected from 1981 to 2010. Average wind speeds were obtained from the USA.com website (54) and presented in Table 13. These values represent monthly averages from 1980 until 2010. Unfortunately wind direction could not be obtained, but according to Scott Kirksey from the NMDOT, prevailing wind direction in the area is west.
TABLE 12 Average Temperature and Monthly Precipitation for the Eagle Nest Region (53)
Conversion: 1in = 2.54cm; °F = 1.8 °C + 32.

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<th>Jul</th>
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TABLE 13 Average Wind Speeds for the Eagle Nest Region. Data Presented in mi/h.
Conversion: 1mi/h = 1.61km/h (54)

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Topographical Data

The terrain in the Eagle Nest region is mountainous, but the area of interest is located in a valley. The land upwind from the right-of-way is used for grazing and two types of fences were observed at that location: a 4ft (1.2m) high barbed wire fence that extends north, and a 4ft (1.2m) snow fence that extends south. The snow fence is made of vertical wood slats. Although the fences were built with a gap of 5in (12.7cm) from the ground, shrinking of slats due to weather effects caused them to slide down, closing the gap. The distance from the fence to the edge of the pavement is larger than that at the Clines Corners site, reaching 75ft (22.9m) at that location, but still smaller than the recommended distance of 53 times the height of the fence.

Required Fence Capacity

The length of the fetch in the Eagle Nest area was measured along the prevailing wind direction (west) on an aerial photograph of the test site. As shown in Figure 85, the fetch in this area ranged from 4000ft (1219.2m) to 7000ft (2133.6m).

The relocated precipitation was also taken as 70% of the water-equivalent precipitation over the entire season, which, as mentioned previously provides a conservative value for design purposes. Because of the low average temperatures observed in the Eagle Nest region, it was assumed that all precipitation from October to April was snow. Therefore, the average total snowfall for a season is 7.38in (18.7cm) of water-equivalent precipitation and the relocated precipitation 5.17in (13.1cm).
The relocated precipitation and the length of the fetch were then used to determine the seasonal snow transport. According to Figure 64, for a fetch of 4000 to 7000ft (1219 to 2134m) and a relocated precipitation of 5.17in (13.1cm), the seasonal snow transport in Eagle Nest is estimated at 35 to 48 tons/ft (104 to 143t/m). The required fence height is then determined using Figure 65. According to the seasonal snow transport estimated for the Eagle Nest site, a 10 to 12ft (3 to 3.7m) snow fence is recommended.

**Snow Fence Location and Orientation**

Because the prevailing for the study site was determined to be 270° (west winds), the angle of attack is 90°, requiring that fences be placed parallel to the road. The ideal setback distance should be 35 times the height of the fence, that is, 350ft (106.7m) if the 10ft (3m) fence is selected or 420ft (128m) if the 12ft (3.7m) fence is used.

**CONSTRUCTION OF SNOW FENCE AT THE EAGLE NEST TEST SITE**

Owners of land adjacent to the proposed test sites in both Eagle Nest and Black Lake regions were contacted by NMDOT regarding the possible placement of snow fences on their property. Unfortunately, neither one agreed to grant the NMDOT access to their land. Instead of condemning the land or selecting a third site, the Technical Panel decided to seize the opportunity to investigate the possibility of developing a new configuration that could be used in constricted sites. The most predictable option would be to reduce the porosity of the fence,
shortening the length of the drift. However, as shown in Figure 16, even if the porosity were reduced to 0%, that is, if a solid fence were to be used, drifts would have a length equal to 13 times the height of the fence, which in this case would be 130ft (39.6m) for a 10ft (3m) fence and 156ft (47.6m) for a 12ft (3.7m) fence. Since the distance from the existing right-of-way fence to the edge of the pavement was measured as 75ft (22.9m), part of the drift of these fences would still be formed over the roadway.

Consequently, Dr. Budek-Schmeisser proposed a more promising configuration composed of two parts: a 4ft (1.2m) vertical lath fence on the bottom, and 4ft (1.2m) of horizontal rails on top, as shown in Figure 55. As mentioned in the section of this report related to Computational Fluid Dynamics Analyses (Task 4), the idea was to let the 4ft (1.2m) vertical lath fence store snow until it becomes buried and a somewhat leveled surface is created on either side of the system. At this point, the horizontal rails placed at the top of the structure would start creating a lenticular drift over the already stored snow, creating a deep drift very close to the structure. As described previously results of the CFD analysis were promising. However, after talking to Neil Clifford, owner of Perma-Rail International, Dr. Budek-Schmeisser changed the design plans. This is because Mr. Clifford who is very experienced in the design and construction of snow fences believed that the velocity of the wind channeled between the top of the vertical lath fence and the bottom rail of the horizontal fence placed above it would be very high, therefore not allowing the formation of a drift above the snow accumulated by the buried 4ft (1.2m) fence. Mr. Clifford proposed the following options instead: (1) two 4ft (1.2m) vertical lath fence, one above the other; (2) two 4ft (1.2m) vertical lath fence, one on the edge of the right-of-way and another halfway between the first fence and the edge of the pavement; or (3) one 8ft (2.4m) vertical lath fence on the edge of the right-of-way and a 4ft (1.2m) vertical lath fence halfway between the first fence and the edge of the pavement. Although these suggestions were seriously considered, the research team strongly recommends against placing snow fences between the edge of the right-of-way and the pavement since it could be a hazard to out-of-control motorists. Therefore, suggestion (A) seemed the only feasible solution. However, the research team thought it impractical to place one 4ft (1.2m) vertical lath fence above another and decided instead to build a custom wooden fence, 8ft (2.4m) tall, with vertical slats and 50% porosity. Although placing this fence on the edge of the right-of-way will probably still cause part of the drift to form in the roadway, it is believed that more snow will be stored close to the fence than with the existing 4ft (1.2m) vertical slat fence. For this custom fence, Dr. Budek-Schmeisser specified 8”x10” (20.3cm x 25.4cm) posts, 11ft 4½in (3.5m) on center, embedded 6ft (1.8m). Slats were specified as 1”x 6” (2.5cm x 15.2cm), and horizontal supports as 2”x6” (5.1cm x 15.2cm), as shown in Figure 86. Due to budget restrictions, the total fence length was set at 200ft (61m).

Since the Eagle Nest site is on DOT land, neither biological nor archaeological surveys were needed. Construction started on November 8, 2010. Changes made to the original design on that day and approved by Dr. Andrew Budek-Schmeisser include:

- Substitution of specified 8”x10” (20.3cm x 25.4cm) posts by telephone posts due to unavailability of the former. Since the posts used were round, notches were cut to help connect horizontal rails (Figure 87). A sealant was used to protect notched areas.
- Spacing between posts was changed to 10ft (3m) on center for practicality and better horizontal rail support.
Horizontal rails were fastened with 6D galvanized pole barn nails (2 per rail end) as shown in Figure 88 and vertical slats were attached to the rails with 2” (5.1cm) galvanized nails (Figure 89) since Wyoming DOT found screws to be too brittle. Sonotubes® were used as concrete forms for the posts’ foundations and extended 8in (20.3cm) above ground level to provide the required gap at the bottom of the fence and protect the toe of the fence during thawing (Figure 90).

**FIGURE 86 Original Specifications for Snow Fence to be Built at the Eagle Nest Site.**  
Conversion: 1ft = 0.3m; 1in = 2.54cm

Construction lasted 6 days and the only piece of equipment required was a bobcat with an auger attachment. Material cost was $9,168.00 and labor $6,032.00, for a total of $15,200.00. Here again, due to the repetitive nature of the work, the author believes that the construction process could be significantly faster, as workers gain familiarity with the fence configuration.
FIGURE 87 Notched Posts for Snow Fence Construction at the Eagle Nest Test Site

FIGURE 88 Fastening of Horizontal Rails with 6D Galvanized Pole Barn Nails
FIGURE 89 Placement of Vertical Slats

FIGURE 90 Detail of Raised Posts’ Foundations
FIGURE 91 Vertical Slat Wood Fence Built at the Eagle Nest Test Site
TASK 8 – EVALUATION OF BARRIER PERFORMANCE AT TEST SITES

Unfortunately, the winter of 2010-2011 was very dry in New Mexico and snow accumulation at the Eagle Nest and the Clines Corners sites was minimal. Since the snow fence at the Clines Corners site was not completed until the end of March 2011, no visits to the site were conducted during the winter. However, monitoring of the weather conditions through different websites indicated no significant snow accumulation. An unofficial visit to the Eagle Nest site was conducted during the afternoon of February 5, 2011. Although a major winter storm had just passed New Mexico, the Eagle Nest area received very little precipitation. Details of the visit and photographs are provided below.

To allow for the evaluation of the snow fences’ performance under wintery conditions, a no-cost extension to this project until June 2012 was approved by the NMDOT. A site visit to the each test site was conducted during the winter of 2011-2012 to evaluate the effectiveness of the snow fences constructed for this project. The first one was to the Clines Corners site on December 26, 2011 and the second one to the Eagle Nest site on January 7, 2012. A report of the two site visits is also presented in the following.

FIELD EVALUATION OF EAGLE NEST SITE

Winter 2010 – 2011

Although snow accumulation was minimal during the winter of 2010 – 2011, a field visit was conducted during the afternoon of February 5, 2011, immediately after the January 31 to February 4, 2011 winter storm. The weather conditions at 4PM on that day were as follows: cloudy skies, light snow and no wind. Although up to 2ft (61cm) of snow had fallen in some regions of the Sangre de Cristo Mountains during this winter storm, a snow cover ranging from only 1 to 2in (2.5 to 5.1cm) was measured at the Eagle Nest site (Figure 92). Figures 93 and 94 show the negligible snow accumulation observed around the snow fence on February 05, 2011 (a maximum of 3in (7.6cm) was measured in the downwind side of the fence.) However, it was interesting to notice the lack of snow cover in the immediate vicinity of the fences, indicating that the gap under the fence was preventing the accumulation of snow at the toe of the fence. Nevertheless, the insignificant amount of snow accumulation prevented the development of any conclusions at that time.

Winter 2011 – 2012

Unfortunately the winter of 2011-2012 did not bring much snowfall to the test site at Eagle Nest. A visit to the Eagle Nest Site was conducted in the morning of January 7, 2012. The air temperature at 10AM was approximately 41°F (5°C), the sky was clear and there was no wind. The snow cover ranged from 5 to 7in (12.7 to 17.8cm) and the drifts formed downwind from the newly-constructed snow fence only reached a height of 11in (27.9cm) and a length of 28ft (8.5m) measured perpendicular to the fence (Figures 95 and 96). Like the previous year, only a very small drift was formed, but once again, there was a lack of snow in the immediate vicinity of the fence (Figure 97), leading the author to believe that the bottom gap was functioning as
intended, preventing snow accumulation against the fence and consequently burying the structure. As shown in Figure 98 of the adjacent 4ft (1.2m) slat fence, when no gap is present at the bottom of the fence, snowdrifts form on both sides of the structure, initiating the burial of the structure and consequently rendering it inefficient. The difference in drift formation and the effect of the bottom gap can clearly be seen in Figure 99 where part of the smaller 4ft (1.2m) fence is buried on the foreground while the toe of the larger wood fence is clear of snow.

FIGURE 92 Snow Cover Around the Newly Constructed Snow Fences at Eagle Nest. Southwest View (02/05/11)

FIGURE 93 Negligible Snow Accumulation on the Downwind Side of the Newly-Constructed Snow Fence at Eagle Nest – Southwest View (02/05/11)
FIGURE 94 South View of the Insignificant Amount of Snow Accumulated on Either Side of the Newly-Constructed Fence at Eagle Nest (02/05/11)

FIGURE 95 Snow Cover and Snow Drift Downwind from the Newly-Constructed Snow Fence (Southwest View) (01/07/12)
FIGURE 96 Snow Drift Downwind from the Newly-Constructed Snow Fence (North View). Lack of Snow at the Toe of the Fence Showing the Efficiency of the Bottom Gap (01/07/12)

FIGURE 97 Snow Drifts on Both Sides of the 4ft (1.2m) Slat Fence (South View) (01/07/12)
FIELD EVALUATION OF CLINES CORNERS SITE

The test site in the Clines Corners region was visited around 11AM on December 26, 2011, a few days after the winter storm of December 23, 2011. Unfortunately, the MesoWest website (22) that had been used to retrieve precipitation information was not operational on December 24 and 25, 2011 and the total amount of precipitation resulting from the winter storm is not known. Weather conditions at the time of the visit were as follows: clear skies, north-west sustained winds of 31mi/h (49.9km/h), and air temperature of 23°F (-5°C). The snow cover was approximately 10in (25.4cm) and drifts were present downwind from the newly-constructed polymer snow fences, while the 4ft (1.2m) vertical slat wood fence was buried in most places (Figures 99 and 100).

The snow drifts downwind from the polymer fence (Figures 101 and 102) extended for 44ft (13.4m) measured perpendicularly from the toe of the fence, and reached a maximum height of 47in (1.2m), a distance of 20ft (6.1m) from the toe of the fence. The end effect, that is, the smaller amount of snow accumulation close to the end of the fence, is also apparent in Figure 103. Also of interest is that the bottom of the fence remained clear of snow accumulation, allowing the fence to remain functional (Figures 101, 104 and 105). This effect was easily observed on that day due to the high winds and the large amount of snow being transported (Figure 105).
FIGURE 99 Snow Drift Along Polymer Fence and Buried 4ft (1.2m) Slat Fence (Southwest View) (12/26/11)

FIGURE 100 Snow Drifts Downwind from Both Fences (Northeast View) (12/26/11)
FIGURE 101 Snow Drift Downwind from the Polymer Fence (South View) (12/26/11)

FIGURE 102 Detail of Snow Drift Downwind from the Polymer Fence (Northeast View) (12/26/11)
FIGURE 103 End Effect on Snowdrift Downwind from the Polymer Fence (Southwest View) (12/26/11)

FIGURE 104 Bottom of Polymer Fence Remained Clear of Snow Accumulation, Assuring that the Fence Remained Functional (South View) (12/26/11)
As mentioned previously and shown in Figures 99 and 100 and in detail in Figure 106, the smaller slat fence located closer to the road was buried. Although the larger polymer fence was shown to be functioning, it is only capable of retaining “far snow”, that is, snow picked up upwind from the fence. The snow caught in the smaller slat fence is what is referred to as “near snow”, that is, snow that is picked up downwind from the larger fence. Figures 107 and 108 illustrate the difference between “far snow” and “near snow”. Extensive research has been conducted on the contention of “near snow” and recommendations include the use of a 4ft (1.2m) vertical slat fence downwind from the larger fence (29) or the use of snow snakes (55, 56). Snow snakes consist of a “tubular plastic mesh device supported by wire frames” (55), shown in Figure 109. They are not only efficient in snow storage but they also “promote the reestablishment of vegetation by increasing soil moisture, providing shade, and by providing protection from wind and grazing animals” (55). Vegetation in the area between the larger snow fence and the road can also help retain “near snow” (55).
FIGURE 106 Buried 4ft (1.2m) Slat Fence (East View) (12/26/11)

FIGURE 107 Distinction between “Near Snow” and “Far Snow” (I3)
FIGURE 108 Near and Far Snow

FIGURE 109 Drift behind Snow Snake
TASK 9 – IMPLEMENTATION PLAN

The New Mexico Department of Transportation (NMDOT) has been using 4ft (1.2m) vertical lath snow fences to reduce snow drifts on roadways and thus improve motorists’ safety, decrease road closures and plowing costs. Though these structures have been able to store a significant amount of snow, their capacity has been exceeded in several locations. In these cases, snow accumulates on both sides of the fences and completely buries the structures. At that point, the fences lose their effectiveness and without any obstacle to cause snow deposition, additional snow carried by the wind is blown over the buried fence and deposited in the roadway. Therefore, the objective of the Snow Barrier Effectiveness research project is to provide the NMDOT with recommendations for appropriate technology to mitigate problems associated with accumulation of snow along the Department’s right-of-way.

This project was divided in nine tasks: (1) survey of the literature, (2) evaluation of two problematic sites determined by members of the Technical Panel, (3) research legal precedent for the placement of safety structures such as snow fences on private land, (4) determination of critical site parameters affecting the effectiveness of the snow fences, (5) determination of the effects of level of service and cost/benefit analysis, (6) development of a methodology for the selection of effective snow barriers, (7) construction of two snow barriers for evaluation, (8) evaluation of the barriers’ performance, and (9) development of an implementation plan for the methodology developed.

The purpose of this Implementation Plan is to assist the NMDOT in the employment of the findings and recommendations of the research project. It provides guidance in the following phases of the design of a snow fence: (1) site identification, (2) data acquisition, (3) snow fence capacity, and (4) snow fence location and orientation. This plan also includes a Field Guide to be used as a practical guide in field operations. The Field Guide provides a brief introduction to snow fences and the principles of their operation. In addition, it describes the factors affecting snow barriers’ performance: height, length, porosity, bottom gap, and fence placement. It also includes a step-by-step approach to the design and placement of these structures and describes the effects of snow fences on livestock and wildlife. Finally, it lists the required steps to acquire land and the surveys required before construction. Because of the successful results of the work conducted for over 40 years by Dr. Ron Tabler in Wyoming, the design procedure recommended in the Field Guide relies extensively on the papers and reports he published and especially on the “Snow Fence Guide” he prepared in 1991 for the Strategic Highway Research Program, National Research Council (15). Readers desiring additional information on any of these topics are referred to the Final Report generated for this research project.

IMPLEMENTATION OF RECOMMENDED METHODOLOGY

Because the methodology for the design and placement of snow fences has been presented in the Field Guide and the Final Report produced for this research project, it will not be repeated in this document. Instead, for each phase of the design methodology (Figure 57), information is presented regarding the goal of the phase and the main recommendations for implementing the suggested practices/procedures.
It is important to recall that snow fences are designed for prevailing wind direction and anticipated snow accumulation and as such, they are expected to be effective most of the time, not all of the time. In the instances where wind direction and/or snow accumulation vary from the norm, they may not only be ineffective in trapping snow, but they may also cause the formation of drifts in unexpected directions. Because snow fences reduce drift formation on the roadways the majority of the time and such occurrences are expected to be rare, their adoption is recommended by the New Mexico Tech research team.

**Phase 1 – Site Identification**

*Goals*

- Identify sites where snow fences can effectively be used to reduce the formation of drifts on the roadway, improve visibility and/or reduce plowing costs.

- Develop criteria for prioritization since available funds may not always allow for the construction of all the structures needed.

*Recommended Approach*

- Identify sites with one or more of the following recurring problems:
  - snow accumulation on the roadway;
  - poor visibility;
  - loss of traction due to snow and/or ice on the roadway;
  - buried snow fences;
  - extensive plowing demand.

- Since snow fences can only capture snow blown by the wind, the only sites that should be considered are the ones with a fetch upwind of the problematic road section, that is, an open area where snow from the ground cover can be picked up by the wind.

- The following parameters can be used to prioritize the candidate sites:
  - accident records for the previous 5 years;
  - road closure history for the previous 5 years;
  - plowing records for the previous 5 years;
  - route’s importance to the region;
  - average daily traffic (ADT).

  Priority should be given based on the seriousness of the problem, that is, the number and severity of accidents, the frequency and duration of road closures, and the extent of plowing requirements, while considering the importance of the roadway to the region and the ADT in the area.

- Consider benefits and costs of different possible countermeasures, for example:
  - design and installation of a snow fence;
o removal or relocation of obstruction causing the formation of the drift on the roadway (structure, vegetation, etc.);

o replacement of w-beam guardrails or concrete barriers with cable barriers (16, 20);

o regrading:
  ▪ a backslope of 7:1 or less on both sides of the road will reduce snow accumulation on the shoulder and pavement (20);
  ▪ creating a terrace backslope on both sides of the road will provide additional storage at the toe of the different cuts and away from the shoulder and road (20);
  ▪ elevating the road above the mean annual snow depth plus an allowance for plowed snow accumulation creates storage areas (16);
  ▪ in the case of lanes divided by a median, ensuring that the upwind lanes are either lower than or at the same elevation as the downwind lanes to prevent snow deposition on the latter (16, 20).

Phase 2 – Data Acquisition

Goal

Gather data necessary for determining the required storage capacity of the snow fences.

Recommended Approach

• Collect the following weather data for the site:
  o prevailing wind direction;
  o wind speed; and
  o snowfall.

• Because weather conditions are essential in determining snow fence dimensions and placement, they should be as specific to the site as possible. The presence of microclimates caused by changes in the terrain and in land use may significantly affect snow transport, deposition, and accumulation. Therefore, when possible, field measurements should be made throughout the winter with the use of portable weather stations.

• If a weather station is not available, at a minimum, prevailing wind direction should be determined by observing the orientation of existing snowdrifts. Since weather systems may cause temporary wind shifts, to determine the most common drift orientation, several observations should be made throughout the winter.

• Weather data can often be obtained from dedicated websites such as:
  o World Climate (24)
  o Western Regional Climate Center (53)
  o MesoWest at the University of Utah (22)
  o National Water and Climate Center of the National Oceanic and Atmospheric Administration (NOAA) (57)
  o United States National Climate Program of NOAA (58)
EarthInfo, Inc. (59)

- Determine the length of the fetch, that is, the length of the open area adjacent to the roadway from which snow will be picked up by the wind and transported to the site.
  - The fetch should be measured in the direction of the prevailing wind, from the edge of the roadway until the nearest physical boundary. Examples of boundaries are: ditches, valleys, structures, fences, streams, lakes, hills, etc.
  - The fetch can be measured on the field, on aerial photographs, or satellite images.

**Phase 3 – Required Fence Capacity**

**Goals**

- Determine the required storage capacity of the snow fences.
- Determine required fence height and required number of fence rows.

**Recommended Approach**

- If temperatures at the site are expected to be low enough to prevent snow to melt throughout the season:
  - Estimate total precipitation (in water equivalent) to be equal to 10% of the average annual snowfall (in inches).
  - Estimate relocated precipitation (amount of snow expected to be transported by the wind and reach the snow fence) to be equal to 70% of the total precipitation.
  - With the length of the fetch measured and the relocated precipitation calculated, use Figure 64 to determine the total seasonal transport – this is the fence required storage capacity.
  - With the required storage capacity, use Figure 65 to determine the fence height and the number of fence rows needed.

- If winters in the areas considered are relatively mild and not all precipitation during the season is snow, or if snow is expected to melt between snow storms, using the relocated precipitation for the entire season to determine required storage capacity may be too conservative. In these cases, instead of using the precipitation (in water equivalent) over the entire season, only the precipitation over the coldest months (when snow would actually be observed) may be sufficient.

- When possible, a single row of tall fences should be used. Not only does it require less space and is less expensive than multiple rows of smaller fences, but it also more effective in improving driver visibility (14, 15).

Although, several types of snow fences are available, the New Mexico Tech Research Team recommends the use of polymer fences with horizontal rails, approximately 50% porosity and a bottom gap of 15% of the fence height. While these structures usually have a higher initial cost
than vertical wood fences, their installation is relatively simple and their maintenance cost is very low. If initial costs for these fences render their use prohibitive, wood fences with horizontal rails, approximately 50% porosity and a bottom gap of 15% of the fence height should be selected. Living fences are not recommended because of the large number of sites not conducive for tree planting in New Mexico, as well as the long period of time required for trees to mature and the fence to become fully functional. Finally, where results of the step-by-step design method presented determine that 4ft (1.2m) snow fences are sufficient for the location in question, vertical lath fences could be selected due to their relatively low cost and ease of installation.

**Phase 4 – Snow Fence Location and Orientation**

*Goal*

Determine the optimal snow fence location and orientation.

*Recommended Approach*

- Determine prevailing wind’s angle of attack, that is, the angle between the prevailing wind’s direction and the roadway (Figure 66).

- If the angle of attack is between 55° and 90°, the fence should be placed parallel to the road.

- If the angle of attack is smaller than 55°, the fences should be placed perpendicular to the wind direction (Figure 67).

- Fences with 50% porosity on flat terrain should be placed a distance equal to at least 35 times the height of the fence from the edge of the road. Because this distance corresponds to the expected length of the drift when fence capacity is reached, it should be measured along the prevailing wind direction instead of perpendicular to the road. However, if wind direction is expected to fluctuate significantly, the worst case scenario should be considered.

- When required setback distance is not available, denser fences, that is, fences with porosity lower than the recommended 50% may be selected. Although they will produce a shorter drift, they will also have a reduced storage capacity, and hence will be a less effective system.

- Fences should be extended beyond the protected area to intercept winds that deviate up to 30° from the prevailing direction, as illustrated in Figures 66 and 67.

- To provide access through the fence, Type A access configuration shown in Figure 70 with a width of at least 10 to 12ft (3 to 3.7m) and 12ft (3.7m) overlap should be used. Each fence section should be no longer than 1320ft (402.3m), and to accommodate the overlap, they should be angled so that the distance from the fence to the pavement is 12ft (3.7m) further at the end of the fence than at the beginning of the structure.
• If vehicular access must be ensured throughout the winter, it is advisable to place openings as far apart as possible and use configuration Type B (Figure 68), even though it will create an unprotected section on the roadway.

• The setback distance recommended above (35 times the height of the fence) is only valid for fences placed on level terrains, that is, where the slope is less than 15°.
  o Fences placed on a ridge or in areas upwind of a depression will provide additional storage because their drifts will not only be higher, but also more elongated (Figure 68).
  o Fences placed on downward slopes (steeper than 15%) will cause more snow to accumulate on the upwind side of the fence, leading to burial of the fence. The drift on the downwind side of the fence will be elongated, as shown in Figure 68.
  o Fences placed on upward slopes greater than 15% will cause the formation of shorter and shallower drifts on the downwind side of the fence and little or no snow accumulation on the upwind side of the fence (Figure 68).
REFERENCES


(11) Iowa Department of Transportation. Iowa's Cooperative Snow Fence Program. Des Moines, Iowa. 2002.


Snow Barrier Effectiveness

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New Mexico Institute of Mining and Technology

A Research Project Sponsored by
New Mexico Department of Transportation Research Bureau

In Cooperation with
The U.S. Department of Transportation Federal Highway Administration
Outline

- Introduction
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- Project Tasks
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  - Task 2 – Field Evaluation
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  - Task 4 – Analysis Method for Determination of Critical Site Parameters
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Introduction

Snow fences are used to reduce the velocity of the wind on the leeward side of the fence, causing the precipitation of the snow and the formation of a drift close to the fence.
Motivation for the Research

New Mexico Department of Transportation (NMDOT) Maintenance Crew has reported that, although effective in most places, 4ft vertical slat snow fences are reaching their capacity and losing their effectiveness at several locations.

To prevent snow accumulation on the roadway at these locations, crews are required to repeatedly clear these sites, significantly increasing maintenance costs.
Objective

The objective of this research project is to provide the NMDOT with recommendations for appropriate snow barrier technology to mitigate problems associated with accumulation of snow along the Department’s roadways.
Project Tasks

1. Literature Review and State of Practice
2. Field Evaluation
3. Development of Methodology for Legal and Safety
4. Analysis Method for Determination of Critical Site Parameters
5. Effect of Level of Service and Cost/Benefit Analyses
6. Match Analysis Methodology
7. Construction of Snow Barriers for Evaluation
8. Evaluation of Barrier Performance at Test Sites
9. Implementation Plan
10. Research Reports
The objective of this task was to perform a comprehensive literature search and state-of-the-practice survey to assess and ascertain best practices for addressing the problem of traffic hazards presented by snow accumulation along the right-of-way.

This task should include:

- a compilation of published research in snow barrier technology
- research into criteria affecting snow barrier design
- a phone survey of state Departments of Transportation with similar environmental conditions
Common Types of Snow Fence

- Wyoming Barrier
- Vertical Wood Fences
- Living Snow Fences
- Polymer Fences
- 4ft Slat Fence
Factors Affecting Snow Fence Capacity

- Height
  - Higher fences have a higher capacity (although relationship is not linear)
- Porosity
  - Ideally 50%
  - Influences shape and length of drift
- Bottom Gap
  - Approximately 10% of total height
  - Prevents burying of the fence

Efficiency of Bottom Gap on Fences with Horizontal Slats vs. Fences with Vertical Slats (Tabler 2003)
More Factors Affecting Snow Fence Capacity

- **Placement**
  - Perpendicular to prevailing wind
  - Place fence approximately 35H from roadway

- **Length**
  - Extend fence 12H on each end to account for end-effect

End Effect (Tabler 2003)
## Phone Survey

<table>
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<tr>
<th>State</th>
<th>Fences Used</th>
<th>Living Fences</th>
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<tbody>
<tr>
<td>Iowa</td>
<td>Vertical lath fences</td>
<td>Corn rows and soybeans</td>
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<tr>
<td>Idaho</td>
<td>Plastic horizontal rail fences</td>
<td>Do not like them</td>
</tr>
<tr>
<td>Minnesota</td>
<td>Plastic horizontal rail fences</td>
<td>Extensively used</td>
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<tr>
<td>Montana</td>
<td>- Wyoming fences</td>
<td>Trees and shrubs</td>
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<tr>
<td></td>
<td>- Plastic rail fences</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Wyoming fences with fiber reinforced polymer (FRP) rails</td>
<td></td>
</tr>
<tr>
<td>South Dakota</td>
<td>- Temporary rollout fences</td>
<td>Pleased with results for over 20 years</td>
</tr>
<tr>
<td></td>
<td>- Wyoming fences</td>
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</tr>
<tr>
<td>Wyoming</td>
<td>- Wyoming fences</td>
<td>Used</td>
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<tr>
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<td>- Plastic rail fences</td>
<td></td>
</tr>
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<td></td>
<td>- Wooden rail fences</td>
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<tr>
<td></td>
<td>- Wood lath fences</td>
<td></td>
</tr>
<tr>
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<td>- Wyoming fences</td>
<td>Sage, rabbitbush, and one ridgetop location with</td>
</tr>
<tr>
<td></td>
<td>- Plastic horizontal rail fences</td>
<td>trees as a test</td>
</tr>
<tr>
<td></td>
<td>- Metal horizontal rail fences (old guardrails)</td>
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Field Evaluation

The objective of this task was to visit the sites selected by the Technical Panel to document existing snow barriers and to evaluate their effectiveness.

- Two test sites were selected by members of the Technical Panel: one in the Clines Corners area and one in the Eagle Nest area.
- Site visits were conducted in the summer of 2009 to evaluate site conditions.
- The sites were visited again in the winter of 2009-2010 to:
  - assess the performance of the existing snow fences
  - understand the magnitude of the problems encountered
  - become familiar with the sites under wintery conditions
Summer Visit to Clines Corners Site

Test Site is located on US 285, less than a mile south of the I-40 intersection.

It was selected due to the recurring problems with snow drifts on the road.

Northwest view of test site and existing 4ft snow fence

July 23, 2009
Winter Visit to Clines Corners Site

Southwest view of snow drift along existing fence on US285

January 31, 2010
Summer Visit to Eagle Nest Site

Test Site is located on US Hwy 64, immediately across from the Mountain View Cabins located at 28386 US Hwy 64.

West view of test site. Existing 4ft snow fence and right-of-way fence

July 30, 2009
Winter Visit to Eagle Nest Site

Snow drift and snow walls created by NMDOT Maintenance Crew to increase storage capacity of existing snow fences

January 29, 2010
Project Tasks

Task 1: Literature Review and State of Practice
Task 2: Field Evaluation
Task 3: Development of Methodology for Legal and Safety
Task 4: Analysis Method for Determination of Critical Site Parameters
Task 5: Effect of Level of Service and Cost/Benefit Analyses
Task 6: Match Analysis Methodology
Task 7: Construction of Snow Barriers for Evaluation
Task 8: Evaluation of Barrier Performance at Test Sites
Task 9: Implementation Plan
Task 10: Research Reports
Development of Methodology for Legal and Safety Issues

The objective of this task was to research and document legal precedent for the placement of safety structures such as snow fences on private land.

Although extreme measures such as easement condemnation should be avoided, precedent for such action is also to be investigated.

Because snow fences have been shown to improve public safety by effectively reduce drift formation on the roadways the majority of the time, their adoption is highly recommended by the research team.
Legal Issues

Opposition to the placement of snow fences on private land is not uncommon.

In these cases, landowners’ cooperation is sought by showcasing the benefits of the structures:
- Improved traffic safety
- Shade for cattle and wildlife during summer
- Shelter for cattle and wildlife during winter
- Melting of trapped snow assists with the watering of rangeland

Minnesota is the only state that has had to resort to condemning land for the construction of snow fences.
(State of Minnesota v. David Dorow et al)

Most states contacted during the phone survey avoided the use of eminent domain.

A special application of eminent domain relates to the condemnation of easements which considers land use instead of land ownership.
NMDOT Practice

- Snow fences often need to be placed on private land.
- Because NMDOT personnel need access to the fence easements have been granted: landowner receives compensation and retains the title of the land, while NMDOT personnel are granted permission to work in a specified area of the property.
- This agreement is often reached once the landowner understands the advantages of the snow fences to public safety, with the added bonus of providing shade and shelter for cattle, and increasing snow storage and hence soil moisture for the growth of forage for livestock.
Placing Snow Fences on Private Land

- Determine area needed for construction and maintenance of the structures
- Contact the Right-of-Way Bureau Chief requesting a Title Report
- Contact the Right-of-Way Bureau and provide:
  - Information on snow fences to be constructed,
  - Maps with proposed location of fences and easements,
  - Title of the land,
  - Final maps and legal descriptions,
  - Appraisal of the land.
- A meeting will be set up with the landowner or lessee to discuss the possibility of an agreement.

Details in Right-of-Way Handbook:
http://dot.state.nm.us/Infrastructure/ROW_Handbook.pdf
Project Tasks

1. Literature Review and State of Practice
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8. Evaluation of Barrier Performance at Test Sites
9. Implementation Plan
10. Research Reports
Analysis Method for Determination of Critical Site Parameters

The goal of this task was to examine and prioritize site parameters that influence the selection of snow barriers.

Since snow fences can only capture snow blown by the wind, only sites that with a fetch upwind of the problematic road section should be considered.
The following parameters can be used to prioritize the candidate sites:

- accident records for previous 5 years;
- road closure history for previous 5 years;
- plowing records for previous 5 years;
- route’s importance to the region;
- average daily traffic (ADT).

Priority should be given based on the seriousness of the problem, that is, number and severity of accidents, frequency and duration of road closures, and extent of plowing requirements, while considering the importance of the roadway to the region and the ADT in the area.
Snow Fence Selection

Parameters dictating snow fences’ effectiveness include:

- height
- orientation
- placement
- porosity
- length
- bottom gap

The New Mexico Tech Research Team recommends polymer fences with horizontal rails, 50% porosity and bottom gap of 15% of the fence height.

If initial costs for these fences render their use prohibitive, wood fences with horizontal rails, 50% porosity and bottom gap of 15% of the fence height should be selected.

Living fences are not recommended because of the large number of sites not conducive for tree planting in New Mexico, as well as the long period of time required for trees to mature and the fence to become fully functional.
Project Tasks

1. Literature Review and State of Practice
2. Field Evaluation
3. Development of Methodology for Legal and Safety
4. Analysis Method for Determination of Critical Site Parameters
5. Effect of Level of Service and Cost/Benefit Analyses
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Effect of Level of Service and Cost/Benefit Analyses

Task 5 aims to investigate:

- the effect of level of service on snow barrier efficiency
- costs and benefits of snow fences
Effect of Level of Service

• Intuitively: the larger the volume of vehicles and the higher their speed, the larger the amount of drifted snow dissipated.

• To accurately determine the effects of level of service on snow barrier performance, field experiments would have to be conducted. At this time, these experiments are cost-prohibitive.

• The author believes that even if the amount of snow dissipated by traffic could be quantified and related to a certain level of service, these values should NOT be used in design because levels of service vary significantly within a 24-hour period.
# Installation and Maintenance Costs

To allow for comparison, costs reported were converted to present value (October 2011) using historical cost indices provided by RS Means.

<table>
<thead>
<tr>
<th>Snow Fence Type</th>
<th>Height (ft)</th>
<th>Initial Cost/ft ($)</th>
<th>Service Life (years)</th>
<th>Maintenance</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wyoming fences (wood)</td>
<td>6</td>
<td>29.08</td>
<td></td>
<td></td>
<td>Tabler and Furnish (1982)</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>35.65</td>
<td></td>
<td></td>
<td>Tabler and Furnish (1982)</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>17.92</td>
<td>25</td>
<td></td>
<td>Jairell and Schmidt (1991)</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>41.54</td>
<td></td>
<td></td>
<td>Tabler and Furnish (1982)</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>53.48</td>
<td></td>
<td></td>
<td>Tabler and Furnish (1982)</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>19.35*</td>
<td>20-25</td>
<td>Maintenance costs are estimated at $6428.40/MI/year.</td>
<td>Laramie County Conservation District</td>
</tr>
<tr>
<td>6 - 14</td>
<td></td>
<td></td>
<td></td>
<td>Annual maintenance costs are estimated at 5% of the initial cost.</td>
<td>Tabler and Meena (2006)</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>18.90**</td>
<td></td>
<td>Very labor intensive and required on an yearly. Example: 3 months were required for a crew of 3 to 4 men to check anchors, tighten bolts and repair fences on a 13-MI stretch of roadway.</td>
<td>Alhenius, pers. com. (2010)</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>29.99**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>28.84**</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Year in which cost was incurred is not known

**Bid price – does not include additional costs due to change orders
## Installation and Maintenance Costs (cont.)

To allow for comparison, costs reported were converted to present value (October 2011) using historical cost indices provided by RS Means.

<table>
<thead>
<tr>
<th>Snow Fence Type</th>
<th>Height (ft)</th>
<th>Initial Cost/ft ($)</th>
<th>Service Life (years)</th>
<th>Maintenance</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vertical wood</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>29.36**</td>
<td></td>
<td>Annual maintenance is required and includes checking of the anchors, tightening of the bolts, and repairs in general.</td>
<td>Alhenius, pers. com. (2010)</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>46.05**</td>
<td></td>
<td></td>
<td>Schroeder (2010)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15.87</td>
<td></td>
<td>Maintenance costs in a 40-mi road stretch in the state of Washington are estimated at $5,000/mi/year.</td>
<td></td>
</tr>
<tr>
<td><strong>Polymer</strong></td>
<td></td>
<td>60.49**</td>
<td></td>
<td>Require very little maintenance. These structures have been in place for 3 years and so far only tightening of the straps have been necessary. Tightening of the bolts is anticipated in the future.</td>
<td>Alhenius, pers. com. (2010)</td>
</tr>
<tr>
<td><strong>Vertical lath fences</strong></td>
<td>4</td>
<td>2.01**</td>
<td></td>
<td></td>
<td>Alhenius, pers. com. (2010)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5 – 7</td>
<td></td>
<td></td>
<td>USDA (1999)</td>
</tr>
<tr>
<td><strong>Living fences</strong></td>
<td>3 rows</td>
<td>4.36*</td>
<td>50-75</td>
<td>Maintenance costs are estimated at $1029.60/mi/year.</td>
<td>Laramie County Conservation District</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Maintenance costs are expected to be very low and consist of only weed control and replanting during the first few years.</td>
<td>Schroeder (2010)</td>
</tr>
</tbody>
</table>

*Year in which cost was incurred is not known

**Bid price – does not include additional costs due to change orders

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Benefits

Reports on the benefits of snow fences varied, but fell into three categories: savings in snow removal costs, reduction in crash rates and road closures.

Tabler (1997 in Josiah and Majeski 2009) reported that savings from snow removal alone yielded benefit/cost ratios ranging from 9:1 to 46:1.

Reductions of 50% in snow removal costs were observed by Hurlbut (1986).

Tabler (1991) reported more than $\frac{1}{3}$ reduction in plowing costs. Plowing costs were estimated 100 times higher than snow fence installation costs.

Tabler and Furnish (1982) showed that:

- snow fences reduced costs of snow and ice removal by at least a third
- snow fences did not affect road closures because these can occur even if poor visibility is observed in only a small unprotected section of the highway
- highways need to be completely protected by snow fences before reductions in road closure time are observed.

Tabler and Meena (2006) observed a reduction in road closure by an average of 8 days per year, with 73% of the roadway protected by snow fences. Crash rates were also assessed over the 34-year life of the structures and a decrease in the frequency of accidents was observed.
Project Tasks

Task 1: Literature Review and State of Practice
Task 2: Field Evaluation
Task 3: Development of Methodology for Legal and Safety
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Task 5: Effect of Level of Service and Cost/Benefit Analyses

Task 6: Match Analysis Methodology
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Task 9: Implementation Plan
Task 10: Research Reports
Match Analysis Methodology

Task 6 consisted in the development of a match analysis methodology to be presented in a Field Guide that provides NMDOT Maintenance crew a practical guide for the design of snow barriers.
The Field Guide developed includes:

- an introduction to snow fences’ operation
- factors affecting their performance
- a step-by-step approach to their design and placement
- effects of snow fences on livestock and wildlife
- required steps for land acquisition

The design process is broken down into four main steps:

1. Site Identification
2. Data Acquisition
3. Required Fence Capacity
4. Snow Fence Location and Orientation

Because of the successful results of the work conducted for over 40 years by Dr. Ron Tabler in Wyoming, the design procedure recommended in the Field Guide relies extensively on the papers and reports he published.
Project Tasks

1. Literature Review and State of Practice
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Construction of Snow Barriers for Evaluation

The objective of Task 7 was to use the design methodology presented in Task 6 to design and construct two snow fences for field evaluation.
Construction at the Clines Corners Test Site

Design Specifications:
- Required fence height: 8ft
- Porosity: 50%
- Setback distance: 240-280ft (30 to 35 times fence height)
- Orientation: parallel to road

The New Mexico Tech Research Team selected an 8.5ft tall polyethylene fence because of its reported performance and low maintenance.

Budget available for this fence limited its length to 300ft.
Details of Clines Corners’ Fence

Placement of polyethylene rails and coated wire-stays to minimize movement of the rails between posts

Details of the pre-manufactured polyethylene snow fence placed in the Clines Corners site

Rail attachment to end posts
Top: secured connection
Bottom: ratchet
Construction at the Eagle Nest Test Site

Design Specifications:
- Required fence height: 10-12ft
- Porosity: 50%
- Setback distance: 350-420ft (35 times fence height)
- Orientation: parallel to road

Lack of landowner’s cooperation prevented New Mexico Tech from placing the snow fence at the proper location. Even if porosity was reduced to shorten drift length, and a solid was used, part of the drift would still be formed over the roadway.

A custom 8ft wooden fence with vertical slats was built at the edge of the right-of-way (75ft from roadway). Although this short setback will still cause part of the drift to form on the road, it is believed that more snow will be stored close to the fence than with the existing 4ft fence.
Details of Eagle Nest’s Fence

Details of the custom snow fence placed in the Eagle Nest test site

Foundations were extended above ground to ensure an 8in bottom gap.
Posts were notched and sealed to help rail connections.
Project Tasks

Task 1: Literature Review and State of Practice
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Evaluation of Barrier Performance at Test Sites

Task 8 consists in the monitoring of the snow fences designed and built for this project over a snow season.

Unfortunately, the winters of 2010-2011 and 2011-2012 did not bring a significant amount of snow to the Eagle Nest and the Clines Corners sites.

Visits to Eagle Nest site:
- February 5, 2011
- January 7, 2012

Visits to Clines Corners site:
- December 26, 2011
- Since the snow fence at the Clines Corners site was not completed until the end of March 2011, no visits to the site were conducted during the first winter.
Field Evaluation of Eagle Nest Site
Winter 2010-2011

Visit conducted on February 5, 2011, immediately after the January 31 to February 4, 2011 winter storm.

Although up to 2ft of snow fell in some regions of the Sangre de Cristo Mountains during this storm, a snow cover ranging from only 1 to 2in was measured at the test site.
Negligible snow accumulation observed around the snow fence on February 05, 2011.

However, it was interesting to notice the lack of snow cover in the immediate vicinity of the fences, indicating that the gap under the fence was preventing the accumulation of snow at the toe of the structure.
January 7, 2012
Drifts formed reached a height of 11 in and a length of 28 ft

Geraldo Wilson Jr.
Eagle Nest
Winter 2011 - 2012

Lack of snow in immediate vicinity of fence showing that bottom gap is preventing snow accumulation against the fence.

The difference in drift formation and the effect of the bottom gap can be seen on the figure in the right, where part of the 4ft fence is buried on the foreground while the toe of the larger wood fence is clear of snow.
Field Evaluation of Clines Corners Site – Winter 2011-2012

Visit conducted on December 26, 2011, after the winter storm of December 23, 2011

Snow cover was approximately 10in and drifts were observed by the polymer snow fences, while the 4ft vertical slat wood fence (on the foreground) was buried in most places.
Snow drifts downwind from polymer fence extended for 44ft, and reached a maximum height of 47in, a distance of 20ft from the toe of the fence.
The bottom of the fence remained clear of snow accumulation, allowing the fence to remain functional.
Project Tasks

Task 1: Literature Review and State of Practice
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Task 9: Implementation Plan
Task 10: Research Reports
In this task, an implementation plan was developed to assist the NMDOT in the employment of the findings and recommendations of the research project.
Project Tasks

- Task 1: Literature Review and State of Practice
- Task 2: Field Evaluation
- Task 3: Development of Methodology for Legal and Safety
- Task 4: Analysis Method for Determination of Critical Site Parameters
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- Task 10: Research Reports
Documents produced as part of this project include:

- Final Report
- Field Guide
- Implementation Plan
- Multimedia Presentation
Conclusions

Snow fences are designed for prevailing wind direction and anticipated snow accumulation and as such, they are expected to be effective most of the time, not all of the time.

In the instances where wind direction and/or snow accumulation vary from the norm, they may not only be ineffective in trapping snow, but they may also cause the formation of drifts in unexpected directions.

Because snow fences reduce drift formation on the roadways the majority of the time and such occurrences are expected to be rare, their adoption is recommended by the New Mexico Tech research team.
Acknowledgments

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This research would not have been possible without the assistance and proficiency of Keli Daniell, project manager for this contract and Deirdre Billingsley, contract administrator.

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They were essential members of the research team and this project could not have been completed without their valuable and extensive contribution.
References


