Highway 26 Transportation Study: Snow Drifting Assessment Study

Agreement #2007-E-0009

Town of the Blue Mountains/Collingwood/Stayner Area
Counties of Simcoe and Grey

December 20, 2010

Submitted to AECOM Canada
Client: Ontario Ministry of Transportation, Central Region

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# Revision Log

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<th>Revised By</th>
<th>Date</th>
<th>Description</th>
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<tr>
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<td>Included the snowdrifting severity index.</td>
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1 Introduction
Snow drifting is a phenomenon that occurs when the wind speed is strong enough to introduce sufficient drag and lift forces on fallen snow to overcome the bonding forces between the snow particles resulting in the transport of snow near the ground surface.

Snow drifting onto highways and the transport of snow across highways results in reduced driver safety and increased road maintenance costs. Highway route selections should if possible avoid areas with a high potential for snow drifting. The Collingwood/Stayner area of Highway 26, the focus of this study, is well known for experiencing significant snow drifting.

2 Project Scope
This project covers the development of a simple mapping layer to describe the expected snow transport severity within the study area, in particular to delineate areas of high potential for snow drifting issues\(^1\). This layer will be used in subsequent analysis to identify and propose preferred routes for an improved Highway 26 corridor in the Blue Mountains/Collingwood/Stayner area.

3 Study Area
The study area is located along the southern shore of Georgian Bay. It covers the extent from Stayner to Thornbury and includes the city of Collingwood. The analysis for this study was contained within a 40 km by 29 km area as shown in Figure 1.

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\(^1\) Confirmed Feb. 1, 2010 via teleconference with Kevin Jones, AECOM.
Figures 2 and 3 show the land cover and topography within the study area. The study area is a mixture of urban, rural and natural landscapes, all which have an impact on snow transport. Snow drifting tends to be worse in rural areas where farm fields have been harvested leaving little vegetation to prevent the snow from drifting. Most of the agricultural lands are located around Stayner and south of Thornbury. Along the top of the escarpment the land cover is mixed with farm fields, forests and swamp land. The study area also has some significant topographic features, in particular the Niagara Escarpment which protrudes between Collingwood and Thornbury. Topography has an impact on both the wind speed and wind direction which in turn impact snow drifting.
Figure 2 SOLRIS Land Classification over the study area.
Figure 3 Digital elevation model of the study area.
4 Meteorological Analysis

Meteorological analysis was performed to examine the climatic factors which generate conditions where snow drifting can occur. This work served to characterize the study area and to generate input data to the snow transport model used later in this study. Weather data consisting of hourly and daily data were required to run our model. A screening process was used to identify candidate weather stations.

Meteorological data from two of Environment Canada’s weather stations were used in this project. These stations provided high quality data that consistently met the hourly and daily time resolution requirements of this study. Eight weather stations were identified (Table 1 and Figure 4) which contained complete or partial records collected over the past 10 years (2000-2010). Three of these stations provided data at an hourly resolution. For this study, hourly wind speed, wind direction and temperature data is required along with snowfall and/or snow on ground data which is recorded only at a daily resolution.

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Hourly</th>
<th>Period of Record</th>
<th>Precipitation Data</th>
<th>Snowfall Data</th>
<th>Snow on Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collingwood Airport</td>
<td>Yes</td>
<td>1994 – 2010</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Borden Automated Weather Observation System (AWOS)</td>
<td>Yes</td>
<td>1996 – 2005</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Barrie AUT</td>
<td>Yes</td>
<td>1994 – 2003</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Thornbury 3</td>
<td>No</td>
<td>2007 – 2010</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Balaclava</td>
<td>No</td>
<td>2006 – 2010</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Markdale</td>
<td>No</td>
<td>2004 – 2010</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Chatsworth</td>
<td>No</td>
<td>1952 – 2006</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
Collingwood Airport and Thornbury 3 are located within the study area, with the latter station being the only one providing snow-on-ground data as well as daily snowfall and rainfall values which are required to run the snow transport model.

It should be acknowledged that the selection of a single weather station to define wind speed distribution over a large study area has the potential to introduce a certain degree of bias into the results. Collingwood Airport is located in an open agricultural area, 2 kilometres inland from Georgian Bay. Overlake wind speeds tend to be higher than overland and it is likely that locations along the shore of Georgian Bay will experience stronger winds\(^2\). Similarly locations further inland from the airport may experience slightly lower wind strengths. Mesoscale features such as the Niagara escarpment and land cover will also impact wind speeds. There is however no suitable weather station located on the escarpment within the study area that can be used to quantify such differences. The snow transport modelling performed in this study includes a wind model which accounts for changes in wind speed and direction due to changes in topography as well as land cover.

Data from the Collingwood and Thornbury weather stations were downloaded and inserted into a database. A single hourly weather record was generated by merging the hourly wind and temperature data from the Collingwood Airport with the daily snowfall and snow on ground data from the Thornbury 3 weather station. The 2000-2002 weather records from Collingwood were dropped from the analysis as they were found to be incomplete.

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\(^2\) The differential between wind speeds over water and land was found to be highest for lower wind velocities although more pronounced in colder temperatures as found by Resio and Vincent (1977) and Schwab and Morton (1984)
4.1 Winter Season Analysis

A qualitative analysis was performed using daily weather data from Collingwood, combined with the snow-on-ground measurements from the Thornbury 3 station\(^3\). The results indicate that the snow-depth varies throughout the winter season due to frequent melt events. The period between January 1 and the end of March has relatively consistent snow cover and was therefore defined as the Snow Accumulation Season (SAS). The SAS is defined as a period of consistent snow coverage during which snow drifts would grow to their maximum depth. This is an important concept in snow fence design as it determines the relevant time-period of analysis.

4.2 Potential Snow Transport

The potential snow transport (PST) is the maximum quantity of blowing snow that can be expected at a site when fetch distance and other local factors are not considered. It is based on an analysis of hourly wind speed and direction which also takes into account the availability and age of the snow on the ground, requiring that snow must have fallen within the past 48 hours in order for drifting to occur. Analysis of the PST over several winter seasons provides an estimate of the magnitude and direction of blowing snow within the study area. An estimate of the hourly PST can be made from the wind speed using the equation:

\[
Q(t) = \frac{U(t)^{3.8}}{233847}
\]

Where \(Q(t)\) is the maximum hourly snow transport in kg/hr/m and \(U(t)\) is the hourly wind speed measured at 10 metres above the ground surface.

Analysis of the Potential Snow Transport at Collingwood was evaluated over eight winter seasons\(^4\) (2003 to 2010). For each season, a breakdown of the potential snow transport along each wind direction as well as the total PST were calculated. A return period analysis was performed on the total PST for each winter season. A plot of the directional distribution of the PST at Collingwood Airport for the winter seasons analysed is shown in Figure 5.

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\(^3\) Note that the period of record for Thornbury is for 2007-2010 only.

\(^4\) A winter season is defined in this study as the period spanning from November 1 of the previous year to March 31 of the current year.
Figure 5. Seasonal PST values (kg/m/yr) calculated for Collingwood over eight years.

The graph shows that for most years, the dominant direction for snow transport was from the NNW direction. The PST directionality is an important factor to consider since the anticipated alignment of the new roadway will likely be perpendicular to this direction and therefore in the direct path of oncoming snowdrifts.
The return period analysis performed on the available years generated the 2, 5 and 9 year return periods and the PST (Table 2). The concept of return period used here is similar to the one applied in hydrology to estimate and express the probability of recurrence of events such as flooding or specific streamflow values. For this and other snowdrift studies conducted by 4DM, ‘return period’ refers specifically to the probability of recurrence of the maximum snow transport quantity events over a given number of years. Wikipedia has an informative, yet easy to read, overview of the concept of return period\(^5\).

<table>
<thead>
<tr>
<th>Return Period (T)</th>
<th>PST (kg/m/yr)</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>30,063</td>
<td>2010</td>
</tr>
<tr>
<td>5</td>
<td>31,471</td>
<td>2009</td>
</tr>
<tr>
<td>9</td>
<td>44,373</td>
<td>2004</td>
</tr>
</tbody>
</table>

The 2004 winter season was used in the snow transport modeling based on its 9-year return period. Based on Figure 5, this selection should not introduce any directional bias into the results as the directionality of the PST appears consistent for the analysed seasons.

### 5 Snowdrift Modeling

The snowdrift model which was recently developed by 4DM with support from NRC-IRAP\(^6\) program was used to compute the snowdrifting constraints layer. The model is a 2D-gridded snow hydrology model designed to run continuously over a winter season at an hourly time step. A high-level view of the model showing the inputs, outputs and sub-models is shown in Figure 6.

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\(^6\) National Research Council Canada - Industrial Research Assistance Program
There are two core models: the wind field model and the snow transport model. The wind field model is a topographically driven model based on the work of Liston et al (2007) which generates wind speed and direction modifiers based on the surface topography, specifically the slope, aspect and curvature.

The snow-transport model captures the first-order snow physics, modeling both the saltation and turbulent suspension modes of snow transport. Saltation is a form of particle transport in which snow particles are ejected from the snow pack and carried by wind currents for a distance before being returned to the surface. Turbulent suspension occurs at higher wind speeds when the upward turbulent motion of the airflow is able to overcome the force of gravity and the snow becomes suspended in the air column (Figure 7).
Figure 7. Schematic diagram showing saltation and turbulent suspension modes of snow transport.

A two-stage snow storage model is used to account for erodible and non-erodible snow. Erodible snow is snow that is available for transport. Non-erodible snow is snow that has aged and hardened to the point where it becomes resistant to erosion. The snow model also accounts for other key snow processes such as melting and precipitation. The conceptual scheme for the snow transport model is shown in Figure 8.

Figure 8. Conceptual model of the snow transport model.
The model outputs the cumulative snow transport (or flux / Q – see 4.2) and the maximum and final snow depths in a grid (raster) format.

5.1 **Data Preparation**

The model requires two spatial datasets in order to run; the surface roughness layers and a digital elevation model (DEM). 30 m was selected as the model grid size as it provided reasonable model results with a reasonable run time.

The snowdrift model partitions the wind shear on the ground between the non-erodible roughness elements (crop stubble, shrubs and trees) and the erodible surface (snow) based on the work presented in Raupach et.al. (1993). Surface roughness layers are required to define the density of the non-erodible roughness elements. These layers consist of:

- Erodible Surface roughness
- Non-erodible heights
- Non-erodible diameters
- Non-erodible elements per hectare

The surface roughness layers for this project were derived from the MNR LIO Southern Ontario Land Resource Information System (SOLRIS) version 1.2. The SOLRIS dataset, a detailed (15m grid cell size) landcover/land use layer, represents the landscape current to 2002. The SOLRIS land classes present in our study area were re-classed to create reasonable values for each of the four roughness layer types.
The DEM is used as an input into the topographic wind model. The MNR LIO hydrologically conditioned DEM was used in this study. This DEM has a cell size of 10m but contains artifacts that were introduced by the hydrological conditioning process. These artifacts are useful for hydrological modeling but are not useful for our analysis. To eliminate the effects of the hydrological conditioning process over Georgian Bay, the water elevation was set to a constant level. The DEM was re-sampled to 30m and processed to generate the slope, aspect and curvature.
5.2 Model Results

The model was run for the 2004 snow accumulation season (assumed to be from January 1 to March 31) as this period experienced the most severe snowdrifting of the seasons analyzed.

For this assessment, only the cumulative snow transport model results were analyzed. The cumulative snow transport is the total sum of the flux of snow across a given cell from all directions. A summary of the results are provided in Table 4.

Table 4. Statistics of cumulative snow transport for the 2004 snow accumulation season.

<table>
<thead>
<tr>
<th></th>
<th>Cumulative Snow Transport (kg/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>959.7</td>
</tr>
<tr>
<td>Mean</td>
<td>37,642.6</td>
</tr>
<tr>
<td>Maximum</td>
<td>76,073.2</td>
</tr>
</tbody>
</table>

The results are visualized in the map shown in Figure 9. The annual snow transport values (classes) have been rated using the snow drift severity index described in Appendix B. Over 50% of the study area has a severity index of Class 4. Class 2 and 3 comprise 20% and 26% respectively with the remaining portions falling within Classes 1 and 5).
Figure 9. Cumulative snow transport result for the 2004 snow accumulation season. The shoreline of Georgian Bay is highlighted with a black line.
As expected the snow transport is highest along the shoreline of Georgian Bay. The low surface roughness of the ice surface on the bay offers little resistance to the strong north-north-west winds. Once the blowing snow hits the shoreline, the urbanized and forested areas which dominate the shoreline provide resistance to the wind and trap the blowing snow. This results in a significant drop in the snow transport. Within the study area, the snow transport is highest in the agricultural areas south of Thornbury and surrounding Stayner (refer to Figure 2). Within these locations, the snow transport is highest along those areas with a large open fetches oriented in the north-north west direction. The southwestern part of the study area experiences generally less snow transport mainly due to patches of forest and swamp that trap the blowing snow.

6 Conclusions and Recommendations

Analysis of the meteorological data from Collingwood Airport and Thornbury weather stations confirms the assumption that the study area is prone to snow drifting issues. The location of the study area along the southern shore of Georgian Bay results in the formation of high winds from the northwest directions.

A physically-based snow transport model was used to analyze snow transport processes over the study area. Modeling results for the 2004 winter season, the worst winter season analyzed, found that the open agricultural fields south of Thornbury and surrounding Stayner have the greatest potential for snow transport (Classes 4 and 5). Based on our experience this represents significant snow transport, of a magnitude sufficient to require mitigation.

The model results should be interpreted as generalized values for the study area. The model does not take into account site-specific configurations that may result in highly localized snow transport problems. Examples of such configurations are roadway alignment, arrangements of hedges, small scale terrain features or roadway designs (e.g. embankments formed by cut sections) that could have an additional impact on snow drifting.

It is recommended that the selected highway route be re-analyzed again at a higher-resolution during the design phase of the highway extension. The purpose of this analysis would be to:

- Identify at a finer scale the locations where snow drift mitigation will be required.
- Assist in the design and implement appropriate snowdrift mitigation solutions such as snow fencing, ditches and snow hedges.
- Determine the risk of snowdrift encroachment onto the roadway through the analysis of designed cut-sections and roadway embankments.

By performing this detailed analysis early in the design process, cost-effective changes can be made that will reduce the long-term costs associated with winter maintenance and improve road safety.
Appendix A. References


Appendix B. Snowdrifting Severity Index

Table 5 presents a severity classification index for blowing and drifting snow applicable to south and central Ontario based on our professional judgment and experience. The classes are based on ranges of the incoming annual snow transport. This is the total annual mass of wind-blown snow crossing the highway which takes into account both the regional meteorology (snowfall, wind speeds and directions) and local factors (road orientation, ground cover, fetch distance, topography, etc.). Examples of mitigations, which are provided for perspective, represent typical size increments of snowfencing used in Ontario based on treatments which would reduce the total cumulative snow transport for the winter season by 90% for the upper limit of a particular class. The mitigations are assumed to be positioned at the minimum setback distances from the roadway to provide a sense of the snow storage requirements. Additionally, for the higher classes, the highway profile should be designed to prevent or at least reduce the accumulation of snow along cut-sections and to promote self-clearing of the road surface.

Treatment of classes 1 and 2 can be easily accomplished through the use of off-the-shelf snowfencing which is commercially available in 1.2 and 1.8 m sizes. Treatment of classes 3 to 5 requires specialized, custom-built snowfences and/or multiple mitigation approaches. If the drift length is less than the width of the right-of-way, the treatment can be installed permanently along the right-of-way. Otherwise the fencing will need to be installed on private lands and will likely need to be removed at the end of each winter season, adding significantly to the annual costs.
Table 5. Snowdrifting severity classification for the incoming fetch-adjusted annual snow transport.

<table>
<thead>
<tr>
<th>Class</th>
<th>Incoming Annual Snow Transport ($Q_m$) (kg/m/yr)</th>
<th>Example Mitigation *</th>
<th>Fence Height</th>
<th>Required Setback from Road</th>
<th>Likely Hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Less than 1,000</td>
<td>No mitigation required</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>1,000 – 8,000</td>
<td>Single 1.2m wood slat fence, setback 22m from roadway.</td>
<td>1.2m</td>
<td>22m</td>
<td>Icing, visibility</td>
</tr>
<tr>
<td>2</td>
<td>8,000 – 20,000</td>
<td>Two lines of 1.2m wood slat fence with the second fence setback 65m from roadway or single line of 1.8m wood slat fence setback 34m from roadway. Considerations of the road design (embankments) may be required.</td>
<td>1.8m</td>
<td>34m</td>
<td>Icing, visibility, accumulation</td>
</tr>
<tr>
<td>3</td>
<td>20,000 - 33,000</td>
<td>Three lines of 1.2m wood slat fence with the third fence setback 105m from roadway or single line of 2.4m wood slat fence setback 45m from roadway. Considerations of the road design (embankments) may be required.</td>
<td>2.4m</td>
<td>45m</td>
<td>Icing, visibility, moderate accumulation</td>
</tr>
<tr>
<td>4</td>
<td>33,000 - 66,000</td>
<td>Single 3.2m wood slat fence, setback 61m from roadway. Considerations of the road design (embankments) required to prevent accumulation.</td>
<td>3.2</td>
<td>61m</td>
<td>Icing, visibility, severe accumulation</td>
</tr>
<tr>
<td>5</td>
<td>Greater than 66,000</td>
<td>Single or multiple rows of custom sized fencing. Road design essential to minimize snow accumulation on road surface.</td>
<td>&gt;3.2</td>
<td>&gt;61m</td>
<td>Icing, visibility, severe accumulation</td>
</tr>
</tbody>
</table>

*Specified mitigation is for the upper range of the class. Actual mitigation requirements must be designed based on a detailed analysis of the snow drifting conditions, terrain and other factors. Recommended solutions may differ from those used in the examples presented here (e.g. living fences).

The project team's experience on several snowdrifting studies has found that classes 1 and 2 are common for areas north of Lake Ontario (Figure 10). For the highway 404 extension, the snow drifting prone areas were limited to class 1 (1000 - 8000 kg/m/yr). The results of this study indicate the potential for Classes 4 and 5 to the south of Georgian Bay.
The approach used to develop the snowdrift severity classification index presented here is based on the modeling results obtained during the execution of a number of highway snowdrift mitigation projects, supplemented by concurrent field measurements and observations by the project team and guided by feedback from Max Perchanok. The resulting scale is therefore still preliminary in nature and a more detailed analysis and further consultation, one that is beyond the scope of this project, will be required to arrive at a snowdrift classification system that can be used operationally in Ontario.