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Highway 400 – Highway 404 Link (Bradford Bypass) Snowdrift Analysis Report

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Final Report

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1. Acronyms

ECCC	Environment and Climate Change Canada
PST	Potential Snow Transport
Q	Snow flux (kg/m)
Qout	Snow flux (kg/m), mitigation
ROW	Right of Way
SAS	Snow Accumulation Season
SOG	Snow on Ground
SY	Snow Year
UTM	Universal Transverse Mercator

2. Project Scope

The Ontario Ministry of Transportation (the Ministry) has retained AECOM Canada Ltd. (AECOM) to undertake a Preliminary Design and project-specific assessment of environmental impacts for the proposed Highway 400 – Highway 404 Link (Bradford Bypass). The Bradford Bypass (the project) is being assessed in accordance with Ontario Regulation 697/21 (the Regulation).

The Bradford Bypass is part of Ontario's plan to expand highways and public transit across the Greater Golden Horseshoe to fight congestion, create jobs and prepare for the massive population growth expected in the next 30 years. Simcoe County's population is expected to increase to 416,000 by 2031, with the Regional Municipality of York growing to 1.79 million by 2041. The Bradford Bypass has been proposed as a response to this dramatic growth in population and travel demand in the area and the forecasted increase in congestion on key roadways linking Highway 400 to Highway 404.

The Bradford Bypass is a proposed 16.3 kilometre controlled access freeway. that will extend from Highway 400 between 8th Line and 9th Line in Bradford West Gwillimbury, will cross a small portion of King Township, and will connect to Highway 404 between Queensville Sideroad and Holborn Road in East Gwillimbury. There are proposed full and partial interchanges, as well as grade separated crossings at intersecting municipal roads and watercourses, including the Holland River and Holland River East Branch. This project also includes the Preliminary Design integration for the replacement of the 9th Line structure on Highway 400, which will accommodate the proposed future ramps north of the Bradford Bypass corridor. The Ministry is considering an interim four-lane configuration and an ultimate eight-lane design for the Bradford Bypass. The interim condition will include two general purpose lanes in each direction and the ultimate condition will include four lanes in each direction (one high-occupancy vehicle lane and three general purpose travel lanes in each direction). This Report and its findings are based on, and valid for, the project footprint identified within this Report. Should the footprint change or be modified in any way, a review of the changes shall be undertaken, and the report (including adjustments to modeling and analysis) will be updated to reflect the changes, impacts, mitigation measures, and any commitments to future work.

This purpose of this Draft Snowdrift Impact Assessment Report is to determine the severity of snowdrifting at locations along the Highway 400 – Highway 404 Link route referred to as the Bradford Bypass and designated interchanges. Then determine recommended location for applying mitigation treatment and type of measure to reduce snowdrifting.

3. Snowdrift Model Area

A snowdrift modeling area was initially determined. The geographic extent requires a distance of 3 to 4 km of fetch from the highway route to account for the potential snow transport during strong winds. The model area is illustrated in **Figure 1** by the rectangle box.

Figure1. Snowdrift Model for the Highway 400 – Highway 404 Link (Bradford Bypass).

4. Approach

Our approach for analyzing the severity of blowing and drifting snow (herein referred to as just "snowdrifting") for the Bradford Bypass consisted of the following steps:

1. **Climatological Analysis**: A climatological analysis was conducted to quantify the meteorological and snow transport characteristics of the study area. Climatological analysis examines snow on the ground, wind conditions, and potential snow transport to estimate volumes and directionality of moving snow. The Snow Accumulation Season (SAS) was determined using meteorological data. Climatological analysis included multiple SAS to account for interannual variability snow conditions.
2. **Study Area Characterization**: By reviewing the available spatial data, the study area was characterized to account for factors relevant to snow transport (e.g., land cover, and topography). The information was then using in the snow transport modeling.
3. **Snow Transport Modeling**: Snow transport modeling is to quantify the movement of snow over the model area as a snow flux (kg/m), considering site specific condition. To determine snow transport, SnowStream2D model developed by 4DM Inc. was used. SnowStream2D is a 2D gridded numerical snow hydrology model designed to simulate snow transport processes by integrating regional meteorology with local topography and land use in the vicinity of the highway corridor.
4. **Snowdrift Assessment and Mitigation Analysis**: Conduct analysis to determine the severity of snowdrifting and help decide, if and which mitigation measures are warranted. SnowStream2D mitigation

model determines the effectiveness of selective treatment such as fences, trees, and shrubs. Mitigation is risk-based approach using exceedance probability for non-precipitated events.

This document provides a summary of implement these four steps to assess the severity of snowdrifting within the study area, as well as recommendations for mitigation.

5. Climatological Analysis

Weather data was acquired from daily and hourly observations at a meteorological station located close to the study area. Archived climate data was collected and processed for the 2004-2022 period, referred to as "climate analysis period". Data analysis was performed to examine the conditions which would result in snowdrifting. Snowdrifting in this context is a wind driven event that occurs during periods of after snow precipitation, where snow is present on the ground, temperature is below freezing, and wind speeds are sufficient to cause the transport of snow. This is typically 20km/hr and greater within 3 days of snow event. The objective of the climatological analysis is to characterize magnitude, location, and direction of snowdrifting conditions in the study area through a Potential Snow Transport (PST) calculation. The weather data acquired was also used as an input to the SnowStream2D gridded numerical snow transport model. SnowStream2D accounts for localized factors related to snow transport considering snow on the ground, erodible and non-erodible snow surface. Topography in terms of roughness, slope, aspect, curvature, and highway orientation within the study area.

5.1. Meteorological Data

For this study, meteorological datasets included in the analysis came from Environment and Climate Change Canada (ECCC) weather stations. Station selection was based on closest station to the study area, with a sufficiently long observation history, availability of daily and hourly data, quality of data, and availability of key meteorological variables necessary for the snowdrifting analysis: air temperature, wind speed and direction, total precipitation, rain, snow, and snow depth (snow on ground).

Three meteorological stations with recent and sufficiently long observation periods were identified in the vicinity (within 20-25 km) of the study area. **Figure 2** shows the locations of the identified meteorological stations used for snowdrift assess. Table 1 summarizes meteorological observations years available at these stations.

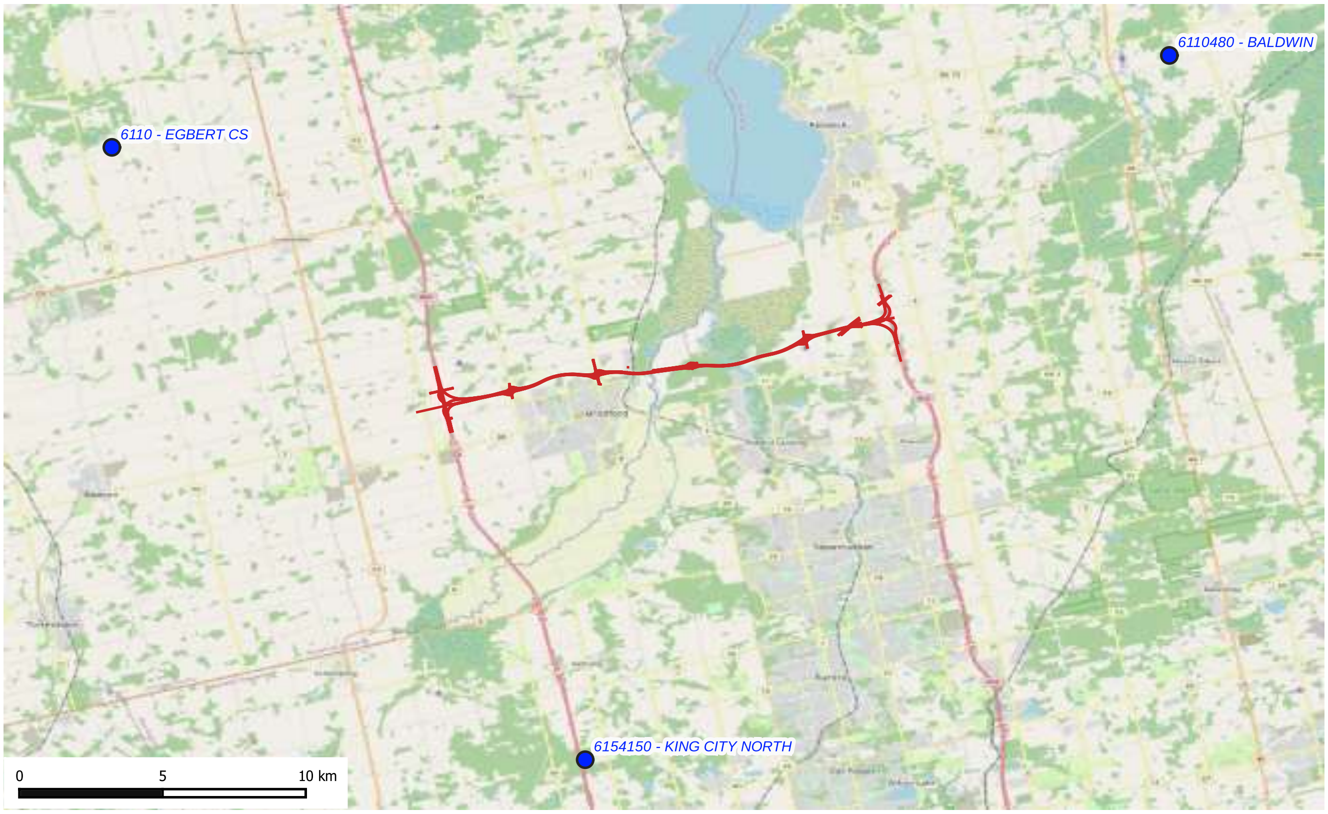

Figure 2 Locations of meteorological stations used for snowdrifting analysis. (BBP route provided by AECOM)

Table 1 Summary of meteorological data used for snowdrifting analysis.

Climate ID	Station Name	Daily Data	Hourly Data
6110 (611E001)	EGBERT CS	2000-2022	2000-2022
6110480	BALDWIN	2004-2022	N/A
6154150	KING CITY NORTH	2019-2022	2019-2022

The EGBERT CS weather station was selected as the primary source of meteorological data since it has the longest recent data observation period for both daily and hourly data. The BALDWIN weather station was used as the secondary data source to fill in the missing daily data obtained from the EGBERT CS station.

Daily meteorological data was pre-processed to fill in missing data values in the total, rainfall, and snow precipitation variables. The following algorithm was applied for filling the missing data:

1. If the total precipitation depth is available:
    a. If one of the rainfall or snowfall depths is missing, the missing value is calculated as the difference between the total precipitation and the other available observation (snowfall or rainfall, respectively). This balance approach is based on the assumption of the typical snow water equivalent (SWE) of 10%, i.e., 1 cm of snow having water content equivalent to 1 mm of water;

b. If both rainfall and snowfall depths are missing, the total precipitation is split into the liquid (rain) and solid (snow) components based on air temperature sing the following logic:

   i. If the maximum daily temperature is 0°C or below, all precipitation is allocated to the snow component;

   ii. If the minimum daily temperature is above 0°C, all precipitation is allocated to the rainfall component;

   iii. In all other cases, the decision is based on the mean daily temperature:

      i) Precipitation is assumed to be snow if the mean daily temperature is below -1°C, and rain if the mean daily temperature is above +1°C;

      ii) If the mean daily temperature is between -1 and +1°C, it is split evenly into snow and rain;

2. If the total precipitation depth is not available:

   a. The total precipitation is set to the sum of rainfall and snowfall is both are available;

      i. In cases where one of the rainfall or snowfall is also missing, the missing values are estimated based on the mean daily temperature as outlined above, if possible (i.e., only snow if the mean daily temperature is below -1°C, and only rain if the mean daily temperature is above +1°C);

   b. If all three precipitation depths are missing the values are copied from the secondary data source (BALDWIN station) for the same day.

In a very few cases data pre-processing as outlined above was not able to fill some missing values; these were subsequently filled manually based reviewing data for adjacent dates.

Hourly data for EGBERT CS station was also downloaded and selectively reviewed for quality issues. No filling was applied to hourly data. Table 2 below shows the missing hourly records from November 1 to April 30th

Table 2 Egbert Hourly Missing Records

Snow Year (Nov 01 to Apr 30)	Total hourly records	Missing hourly records
2005	4344	11
2006	4344	45
2007	4344	1
2008	4368	1
2009	4344	6
2010	4344	7
2011	4344	2
2012	4368	14
2013	4344	4
2014	4344	18

2015	4344	30
2016	4368	54
2017	4344	9
2018	4344	9
2019	4344	11
2020	4368	2
2021	4344	5
2022	4344	0
Grand Total	**78288**	**229**

The percentage of missing records is 0.3%. The missing records has negligible effect on modeling and analysis.

The daily and hourly meteorological data was then loaded into a database for climate analysis and SnowStream2D modeling. The daily meteorological data provides the snow on ground and precipitation amounts. The hourly data provided the temperature, wind speed and direction information.

5.2. Snow Accumulation Season

The climate analysis performed next examined the snow depth characteristics from the selected climate station. Precipitated snow will typically occur between November through to the end of April in Southern Ontario. During this period, fluctuation in temperature results in snow accumulation and melting. When the temperature consistently remains below 0˚C, snow will begin to accumulate. This is known as the Snow Accumulation Season (SAS). From a snowdrifting perspective, the SAS is the temporal period used as the representative snow condition for modeling snowdrifting conditions. Daily snow on ground (SoG) observation from ECCC Egbert, was used to identify SAS for a period from 2004 to 2022. The temporal period defines as the Snow Year (SY) using the starting period from November 1st to April 30th, which is then refined for specific dates based on presence of snow on the ground. The calendar period used for SY, is defined as the calendar year in which the corresponding winter season ends; for example, the 2004/2005 winter season is referred to as the SY2005.

The results of the SAS analysis are illustrated in **Figure 3**. The plot illustrates the timing and magnitude of minimum, mean and maximum snow depth over the SAS for the 18-year climate analysis period from SY2005 to SY2022.

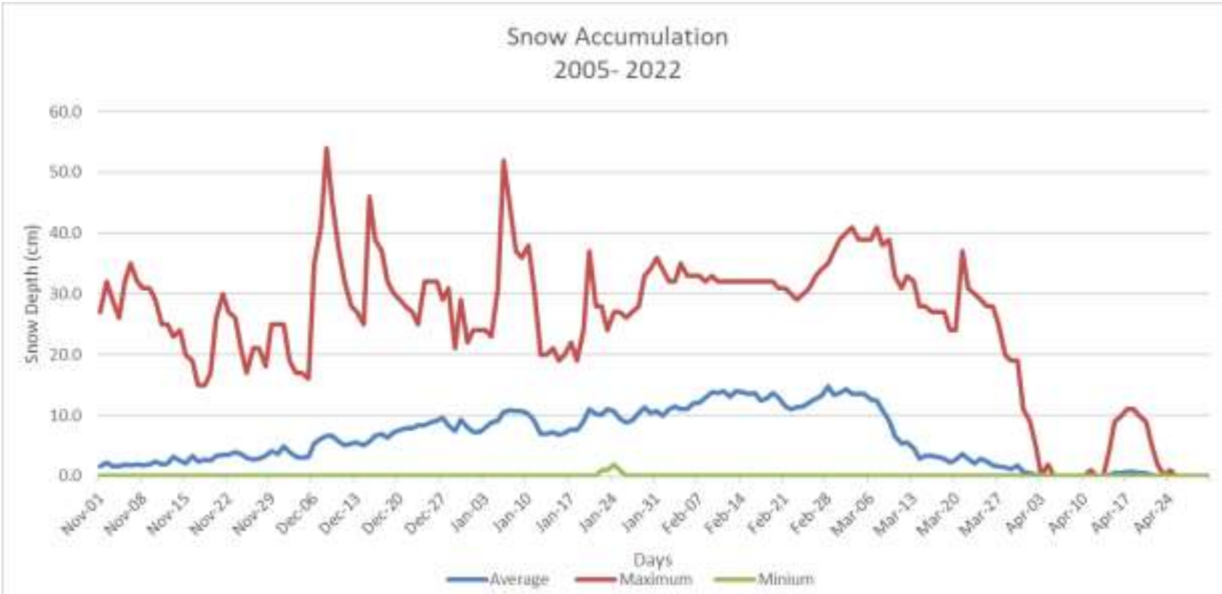

Figure 3 Average snow on ground.

The graph indicates that over the climatological analysis period the average snow on ground occurs from November 1st to April 3rd and that snow events can occur in early November. In addition, the peak snow depth can reach 54 cm.

Figure 4 shows the probability of snow on ground for each day in an average winter season (Nov 1st to April 30th) based on the 18-year SY climate analysis period. The probability is essentially a percent of winter seasons with snow on the ground calculated for each calendar day of the winter season. On average, there are 108 consecutive days (December 1 to March 18) with at least 50% probability of snow being present on ground. 50% is used as reasonable threshold for potential snowdrifting temporal period.

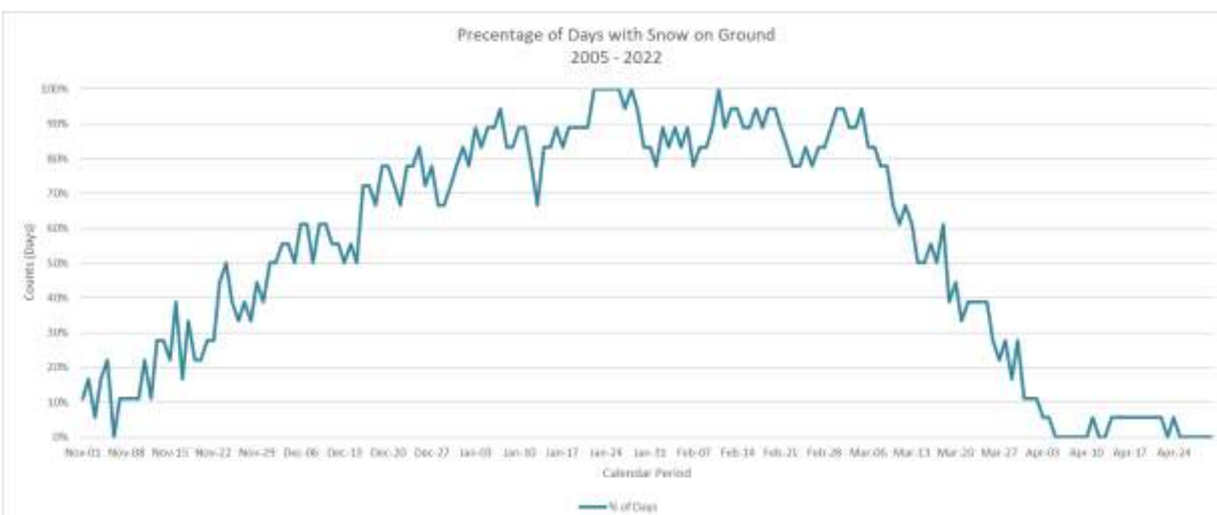

Figure 4 Daily probability of snow on ground based on the SY climatological analysis period.

Figure 5 presents the average SY snow on ground depths over the climate analysis period. On average, the expected average depth of snow on ground over a SY is about 6.1 cm with a standard deviation of 3 cm. Applying a linear trend analysis, a gradual decrease of the average snow depths is observed (trend not tested statistically).

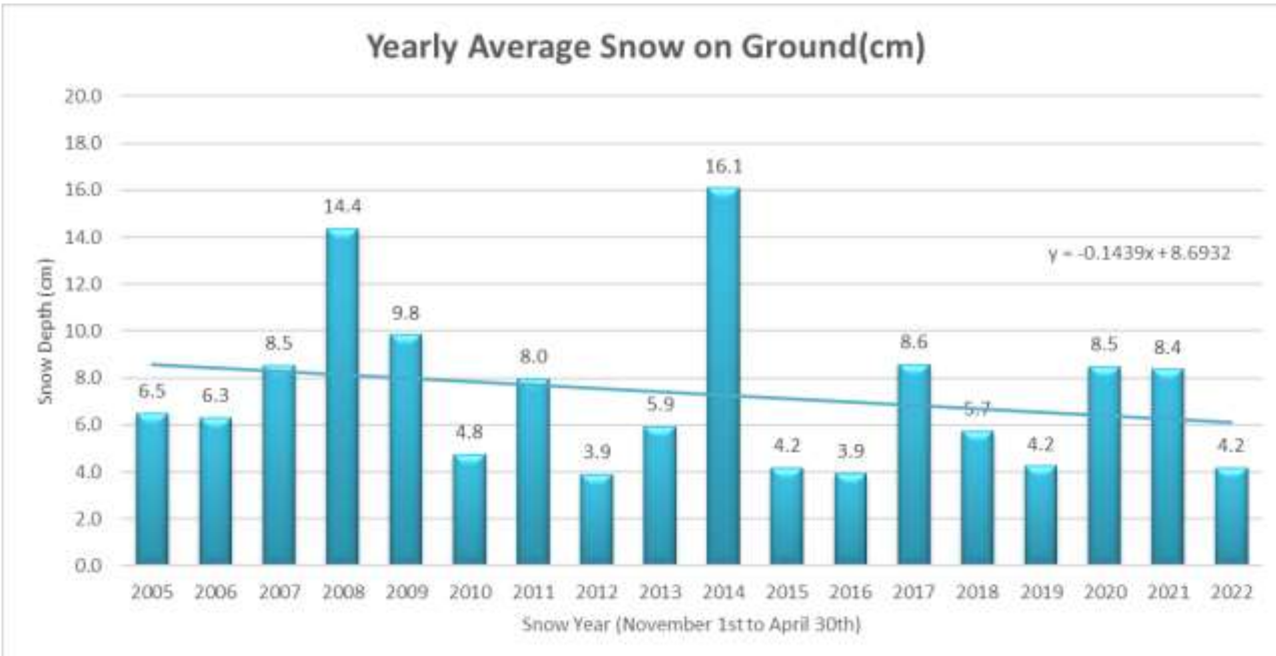

Figure 5. Average snow on ground over the SY periods.

Figure 6 shows the maximum SY snow on ground depths over the climate analysis period. The maximum snow depth varies from 19 cm to 54 cm with a 35 cm range and a standard deviation of 10 cm. The linear trend line also indicates downward decrease over the analysis period; however, it was not statistically tested.

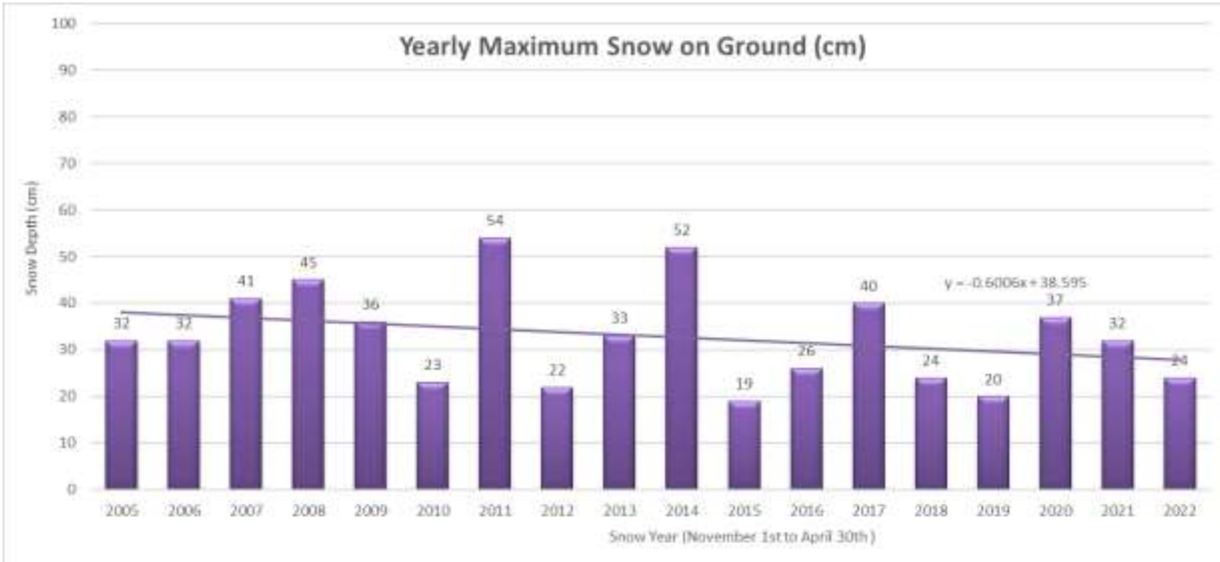

Figure 6. Maximum snow on ground over a winter season (Snow Year).

Analysis was also done to examine the total snow accumulation over a period from November 1st to April 30th of total amount of snow available for snow transport. **Figure 7** indicates that the total snow accumulation varies from 2,892 cm to 670 cm with a range of 2,222 cm and an average over the climatological analysis period of about 1,268 cm. This is equivalent of 22m of snow. On average a cubic meter of fresh snow is equivalent to 50kg. and theoretically for each meter there is potential 1,100 kg/m snow available over average SAS. The trend line on total snow accumulation is also decreasing over time; however, no statistical testing was done to evaluate the trend's significance.

Figure 7. Total snow accumulation over SY climate analysis period

The importance of conducting the snow accumulation analysis is to determine the quantity and temporal pattern of the available snow that could lead to snowdrifting conditions. The snow accumulation data is used as input into SnowStream2D model for the selected snow years to derive the snow flux along the planned highway route. The selected snow years are based on a probability of exceedance derived from a calculation of the possible snow transport for each SY within the climate analysis period.

5.3. Potential Snow Transport

The next step in the climatological analysis was to investigate the magnitude of the Potential Snow Transport (PST). PST is the theoretical maximum quantity of blowing snow that can be expected when local factors, such as ground cover, topography, and road orientation are not considered. It is based on the analysis of wind speed and direction, temperature, and precipitation from the selected climate station from Nov 1st to April 30th. The calculation is conducted during the period when the temperature is below freezing. PST is used as a proxy or reference value to assess the magnitude and direction of blowing snow. PST is a cumulative value expressed in units of mass per meter over a SY (kg/m). It is calculated by classifying the hourly wind data according to the wind speed and direction, then calculating the frequency for each wind speed class and direction. Next, the snow transport for each wind class is calculated and summed for sixteen compass cardinal directions to provide a distribution of PST by direction.

An analysis of PST conducted over SY climate analysis period provides information on the variability in the magnitude and direction of blowing snow near the study area. The PST was calculated from hourly data at the EGBERT CS weather station for the 18 snow years. PST calculation also used the daily climate data from the EGBERT CS station as an indicator of the presence of snow on the ground within a 3 day window to determine potential drifting conditions before snow on ground begins to harden and is limited in contributing to snowdrifting.

For each SY, an hourly calculation was conducted to determine PST for all cardinal directions using data obtained from EGBERT CS weather station. **Figure 8** illustrates year to year magnitude of the PST by Snow Year.

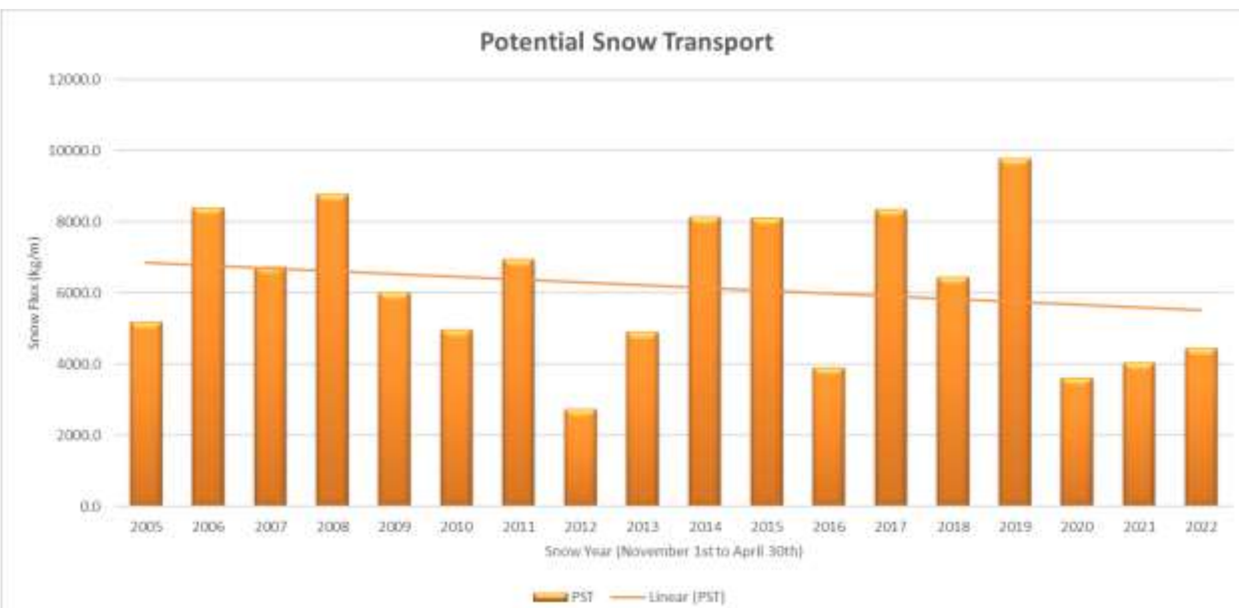

Figure 8. Potential Snow Transport calculated at the EGBERT CS weather station.

The PST exhibits a variation from one snow year to another, ranging from 2,736 to 9,773 kg/m, with an average of approximately 6,193 kg/m. Consistent to all other snow characteristics, it also shows a negative linear trend over the climate analysis period (not tested statistically). **Table 3** shows the PST statistics over the whole climate analysis period.

Table 3 Cumulative PST statistics for SY2005 to SY2022.

Parameter	PST (kg/m)
Mean	6,193
Median	6,231
Standard Deviation	2,017
Minimum	2,736
Maximum	9,773

In addition to the PST presented above, direction-specific PST was calculated using the 16 cardinal wind directions to quantify the dominant wind direction(s) that contribute to snow transport along the highway route. **Table 4** provides the distribution of the mean PST over the climate analysis period by the cardinal direction. The data indicates that 76% from westerly directions (SSW-NNW), 19% from easterly (NE-SE), 1% from north and 4% from south. The distribution is illustratrated by a radar plot in **Figure 9.**

Table 4 Mean PST at EGBERT CS weather station (SY2005-SY2020) by cardinal direction.

Wind Cardinal Direction	Mean Total PST (kg/m)	Percentage PST Direction
N	93	1%
NNE	4	0%
NE	15	0%
ENE	50	1%
E	440	7%
ESE	256	4%
SE	346	5%
SSE	91	1%
S	222	4%
SSW	349	5%
SW	651	10%
WSW	640	10%
W	368	6%
WNW	222	4%

NW	1,175	19%
NNW	1,421	22%
TOTAL	**6,342**	**100%**

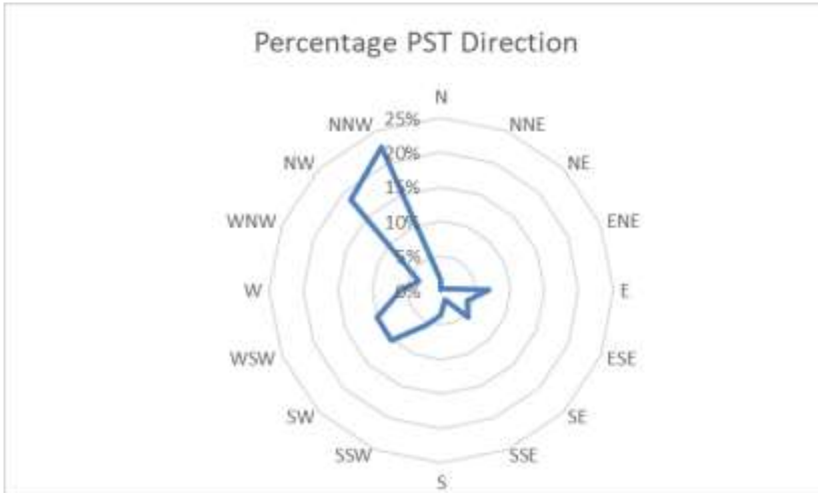

Figure 9. Distribution of PST by cardinal wind direction.

Results presented in **Table 4** and **Figure 10** indicate that the dominant snow transport direction in the study area is generally from northwest to the north-northwest (NW-NNW), referred to as northwesterly with a secondary component from southwest to west southwest (SW-WSW) referred to as southwesterly. However, it should be noted that approximately 12% of the PST comes from the easterly direction (ESE-ENE) as results of synoptic frontal low pressure systems (**Figure 11**). Typically, ahead of the warm front on synoptic low pressure systems, winds originate from the east in a counterclockwise direction. The pressure gradient determines the strength as well as the wind direction and synoptic systems are typically associated with precipitated events. Once the system passes, the cold air on the backside results in a wind shift from northwest to westerly and if snow has fallen snow drifting conditions will likely occur from this direction.

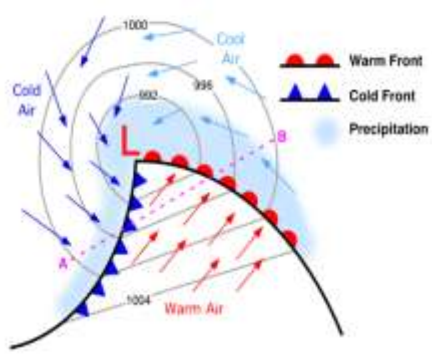

Figure 10. Synoptic scale low pressure system.

From a risk mitigation perspective, the two directional components of PST of significance are from northwesterly and southwesterly, which represents indicators of where drifting snow originates from. The PST calculation provides a theoretical magnitude and direction of snow transport. The magnitude of PST in the study area is moderate to low relative to other modeled areas by 4DM. For example, the mean PST for Highway 26 areas (~37,000 kg/m), Ottawa (~28,000 kg/m), Ancaster (~30,000 kg/m) and Niagara area (~11,000 kg/m). This location is ~ 6,000 kg/m.

5.4. Selection of Snow Years for Snow Transport Modeling

The snowdrift analysis and mitigation process are based on a risk assessment approach. It's not feasible to mitigate for all snowdrifting cases since the quantity snow and the wind characteristics will vary in severity over different snow years. The snowdrift analysis in the study is based on the probability that snowdrifting event occurring. The probability can be expressed using a return period calculation which corresponds to a theoretical probability of an event of occurring of a certain or higher magnitude. In the context of the snowdrift analysis, a 2-year (2-yr) potential snow transport (PST) return period event has a 1/2 = 0.5 or 50% chance of being exceeded in any one given year.

To determine the representative snow years for snowdrift modeling, the distribution of the PST calculated for the 18 snow years was logarithmically plotted to find snow years that are the closest to the theoretical 2-yr, 5-yr and 10-yr PST return periods. A plot of PST magnitude versus return period is shown in **Figure 11**. Plot indicates the SY periods that represent 2-yr, 5-yr and 6.6-yr return period or 50%, 20% and 15% annual exceedance. There was not suitable representative of 10-yr return period. The closest SY period to a 10-yr PST return period was 2008 (SY2008) which has approximately 6.6-yr return period.

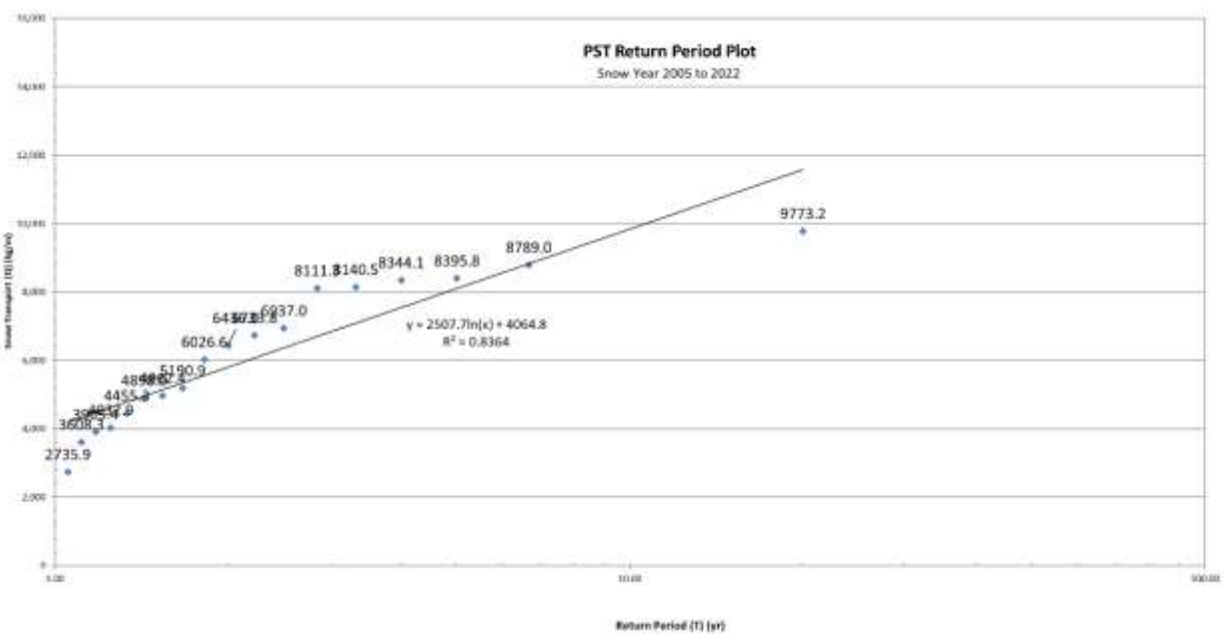

Figure 11. PST return period plot.

Table 5 lists the representative snow years and snow flux (kg/m) values corresponding to the 2-yr, 5-yr and 6.6-yrs return periods based on PST values, for the selected snow accumulation seasons (SAS) calendar period.

Table 5 PST SY Return Period

PST Year	Q (Snow Flux) (kg/m)	Return Period
2008	8,789.02	6.6
2006	8,395.78	5
2018	6,435.96	2

A summary of PST estimate for the selected return periods is provided in **Table 6**. The SAS calendar period of interest was then used to model snow flux (kg/m) on the highway route and interchanges using SnowStream2D.

Table 6 SAS corresponding to the 2-yr, 5-yr, and 6.6-yr potential snow transport return periods.

Snow Year	PST Return Period	Snow Accumulation Season
SY2018	2-yr	December 9, 2017, to February 20, 2018
SY2006	5-yr	December 02, 2005, to March 10, 2006
SY2008	6.6-yr	November 22, 2007, to April 3, 2008

In the context of assessing the severity of snow flux at the highway route, a 2-yr return period represents a common occurrence and as such does not provide broader snowdrift protection. The 5-yr and 6.6-yr return periods correspond to more extreme conditions. The 2006 snow year (SY2006) represents a 5-yr PST return period and was used for snow flux modeling and mitigation. The reason for using 5-yr return period, it represents a balance between common occurrences version more extreme snowdrifting events. **Figure** 12 show the temporal distribution of snow accumulation for SY2006

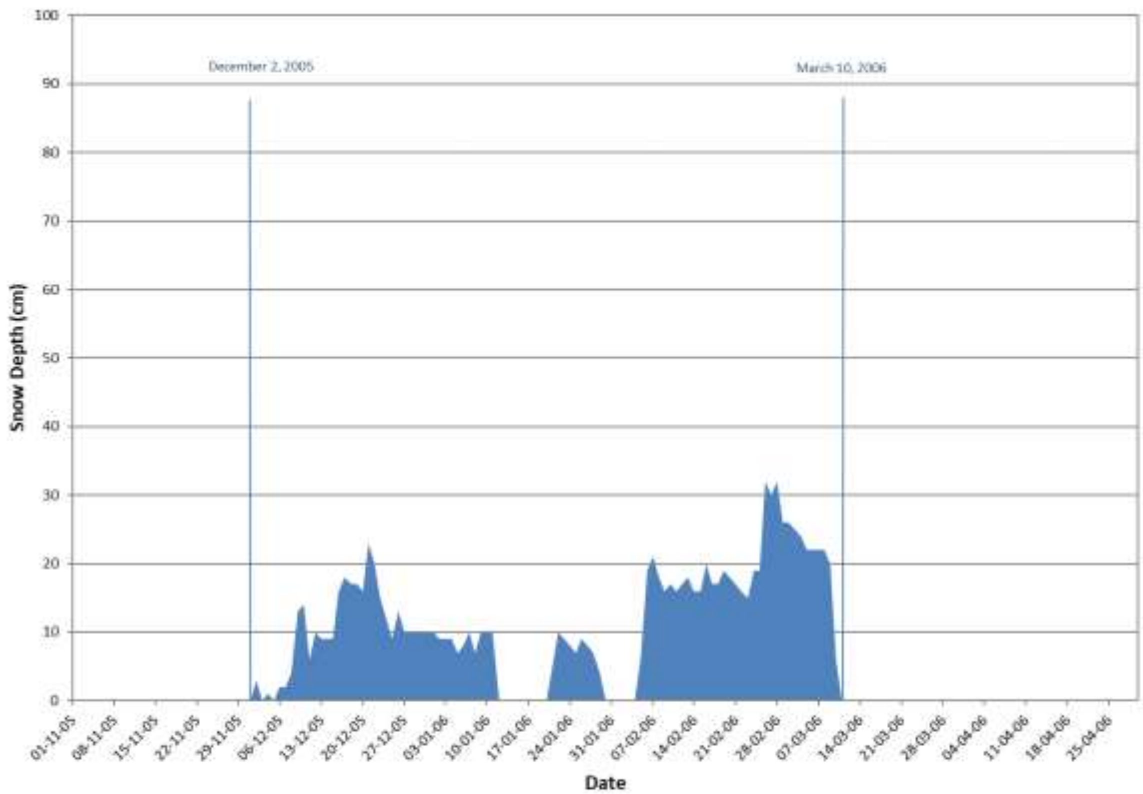

Figure 12. Snow on ground distribution for Snow Year 2006 (SY2006), which corresponds to 5-yr return period.

6. Study Area Characterization

This section describes the characterization of the study area to prepare model inputs for SnowStream2D snowdrift modeling. The tasks involved identifying the model geographic extent, classifying the land cover specific to snowdrifting features, preparing a Digital Elevation Model (DEM), and creating topographic spatial layers derived from DEM.

Satellite and aerial images were used to view and extract land cover details in the study area. The extent of the study area was based on a minimum fetch length from highway route in all direction. The land cover and DEM data were then processed to create input data for SnowStream2D model.

6.1. Land Cover

A modeling study area of 11.5 km x 22.5 km was selected where the highway route shortest fetch distance was at least 3.5 km in any direction. Snow particles across open fetch areas can travel over 3-4 km depending on wind speed, land cover and time. Snow grains become hardened into the snowpack over time and are resistant to movement typically within 1-3 days depending on temperature and humidity. In this modeling area, further geographic extent has negligible contribution to snow transport due to surrounding landscape roughness and the built-up areas provide resistance. In addition, the main snow transport is from northwesterly and southwesterly direction whereby the modeling fetch length is sufficient with respect to the snow transport directions.

Landcover type was classified using open-source data from Land Information Ontario, Agriculture and Agrifood Canada, other land cover data and visual interpretation of imagery. Landcover was created at a 5m resolution. **Figure13** shows the land cover map for the modeling area.

Figure13. Landcover in the study area.

Landcover map data was converted into model input data for the SnowStream2D model. The model accounts for wind shear on the ground between the non-erodible roughness elements (e.g., crop stubble, buildings, shrubs, and trees) and the erodible surface (snow); therefore, surface roughness layers are created to define the density of erodible and non-erodible roughness elements which provides the degree of resistance to snow transport. The following gridded model input layers were prepared using the landcover layer:

- Erodible surface roughness;
- Non-erodible heights;
- Non-erodible diameters; and
- Non-erodible elements per hectare.

The gridded model input layers were then reviewed, and quality checked prior to modeling.

6.2. Topography

A DEM was used as an input into the terrain wind model within SnowStream2D. The DEM data source was obtained from Land Information Ontario for the study area. Elevation data used for Simcoe County was created from photogrammetry at 5m resolution. York Region LiDAR data at 1m resolution was resampled and merged to create a uniform 5m DEM over the modeling area.

To attain the most accurate possible representation of the terrain within the Right of Way (ROW) of the highway route, the DEM was then modified to incorporate digital elevation changes corresponding to cuts and fills, provided by AECOM.

Finally, terrain processing was applied to derive slope, aspect, and surface curvature required as model inputs. **Figure 14** shows the DEM over the model area.

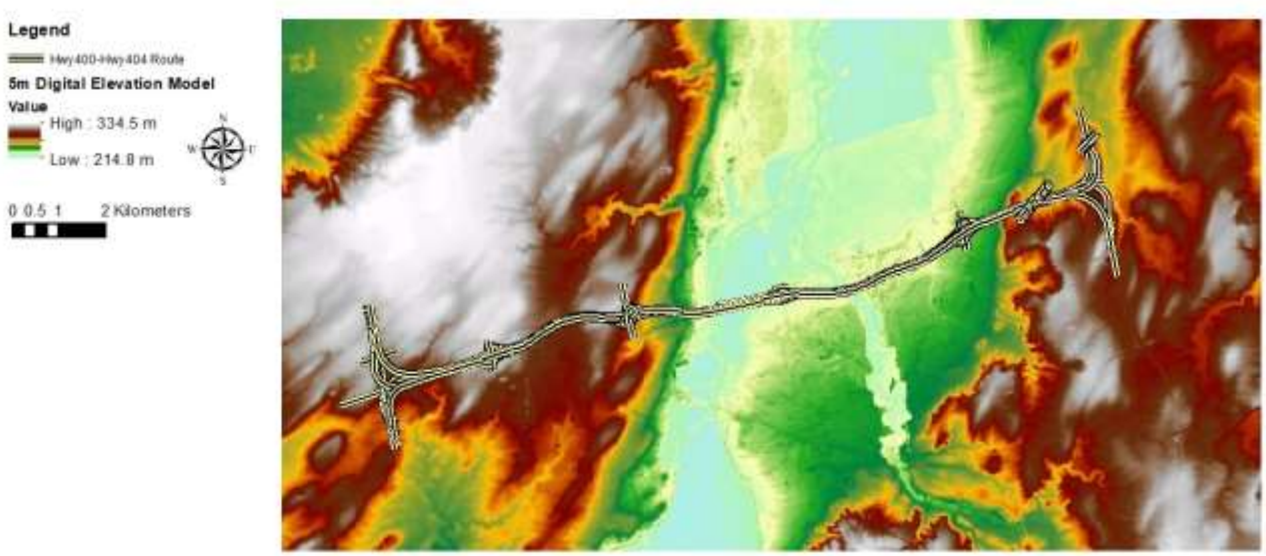

Figure 14. Digital elevation model (DEM) of the study area.

7. Snow Transport Modeling

The climate data, land cover, and topography were utilized in the snow transport model to quantify the snow flux moving across the modeling area and particularly at the highway route and interchanges. The snow transport model accounts for local factors to simulate the cumulative snow transport process from all directions. The snow transport modeling is quantifying the snow flux from the adjacent land onto the highway from any direction from the outside edge of pavement based ultimate 8 lane design. This section outlines the snow transport model that was used to quantity snowdrifting in the study area.

7.1. Snow Transport Modeling

SnowStream2D is a snow transport simulation model, developed by 4DM Inc. with support from the National Research Council Canada-Industrial Research Assistance Program (NRC-IRAP) and was presented at the US Transportation Research Board Winter Symposium (2012). The model was used to compute the total cumulative snow transport over the study area. The SnowStream2D 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 illustrated in **Figure 15**.

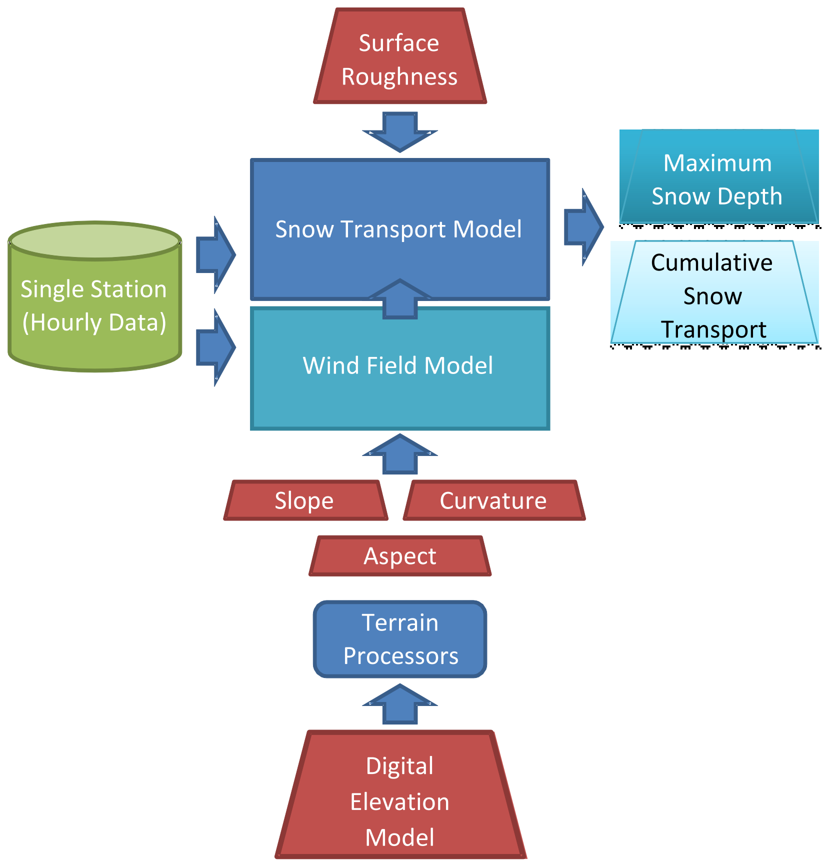

Figure 15. Overview of the SnowStream2D snow transport simulation model.

The SnowStream2D model consists of two sub-models: (i) a wind field model; and (ii) a snow transport model. The wind field model is a topographically driven model that generates wind speed and direction modifiers based on the surface topography.

The processing scheme for the SnowStream2D snow transport model is shown in **Figure 16**. The model captures the first-order snow transport physics, modeling both the saltation and turbulent suspension modes of snow transport (i.e., drifting and blowing snow, respectively).

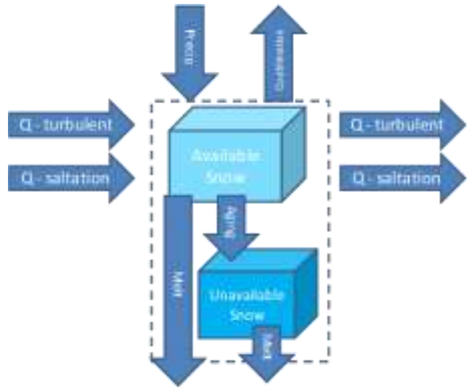

Figure16. SnowStream2D process.

Saltation is a form of particle transport in which snow particles are ejected from the snowpack 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 17**). Snow hydrological processes such as snow storage, sublimation and melt are also included in the model. A two-stage snow storage model is used to account for the volume of erodible and non-erodible snow. Erodible snow is snow that is available for transport whereas non-erodible snow is snow that has aged and hardened to the point where it becomes resistant to wind erosion. The snow model also accounts for other key snow processes such as melting and precipitation. The model outputs the cumulative snow transport at specific locations, such as along the highway route, for further analysis and is inputted into snow mitigation modeling.

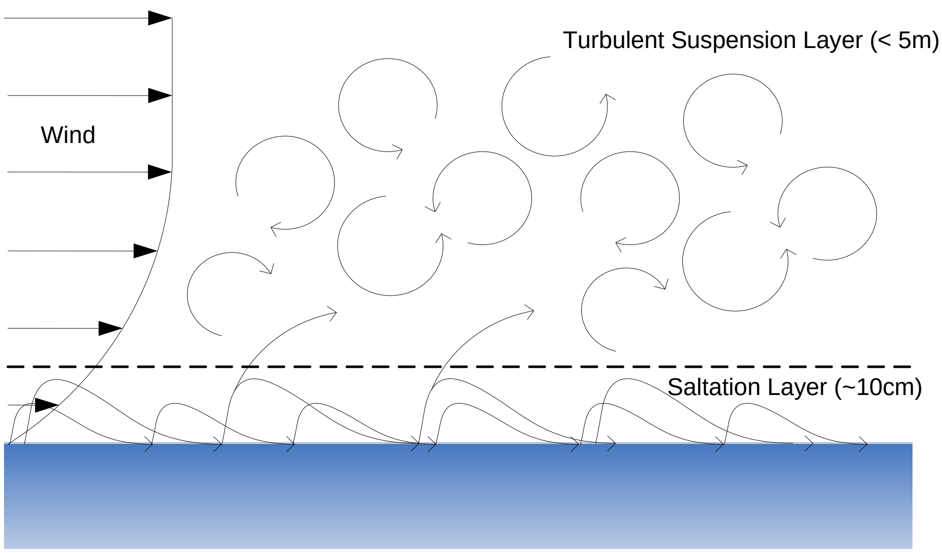

Figure 17. Schematic diagram showing saltation and turbulent suspension modes of snow transport.

The data input for modeling the study area at 5m resolution included the following gridded geographic datasets:

- Erodible surface roughness

- Non-erodible heights
- Non-erodible diameters
- Non-erodible elements per hectare
- Surface curvature
- Surface aspect
- Surface slope

Climate data from a combination of hourly wind and temperature data (Egbert Merged) and with daily precipitation and snow on ground data (Egbert) is also used by the model.

Again, the snow transport model runs were conducted for the following periods:

- SY2008 6.6yr return period November 22, 2007, to April 3, 2008
- SY2006 5 yr return period December 02, 2005, to March 10, 2006
- SY2018 2 yr return period December 9, 2017, to February 20, 2018

Only the SY2006 5yr return period was then used for mitigation analysis.

7.2. Snow Transport Analysis

The model results for SY 2006 shows the cumulative distribution of snow flux across the model study areas in all directions for **Figure 18**. The model calculates the cumulative snow flux for each grid cell in all directions over the SAS accounting for the land cover and terrain. Snow Flux represents a mass of snow blowing across a unit area in meters over the SAS of the model SY (kg/m). The snow flux map illustrates the distribution of snow flux in the study area. The darker blue area represents low snow flux and the lighter area represents higher snow flux. The line profile along the highway route provides the snow flux magnitude in all directions.

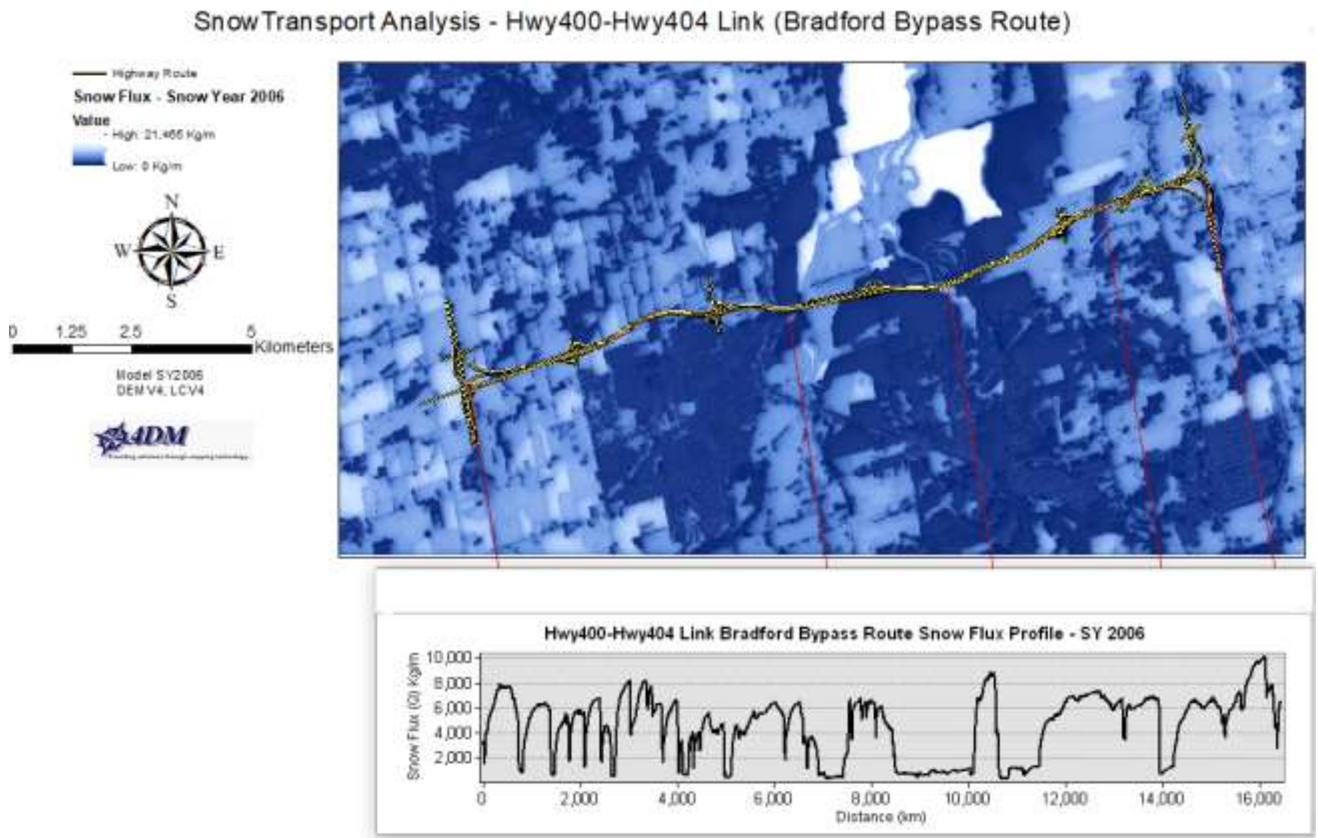

Figure 18 Snow Transport Model 5-yr Return Period - SY 2006

The model results indicated that total cumulative snow flux along the highway route ranges from 2,000 kg/m to just under 10,000 kg/m for a 5-yr return period.

Figure 19 is the snow flux for SY2008 6.6-yr return period where the magnitude ranges from 4,000 kg/m to just under 12,000 kg/m

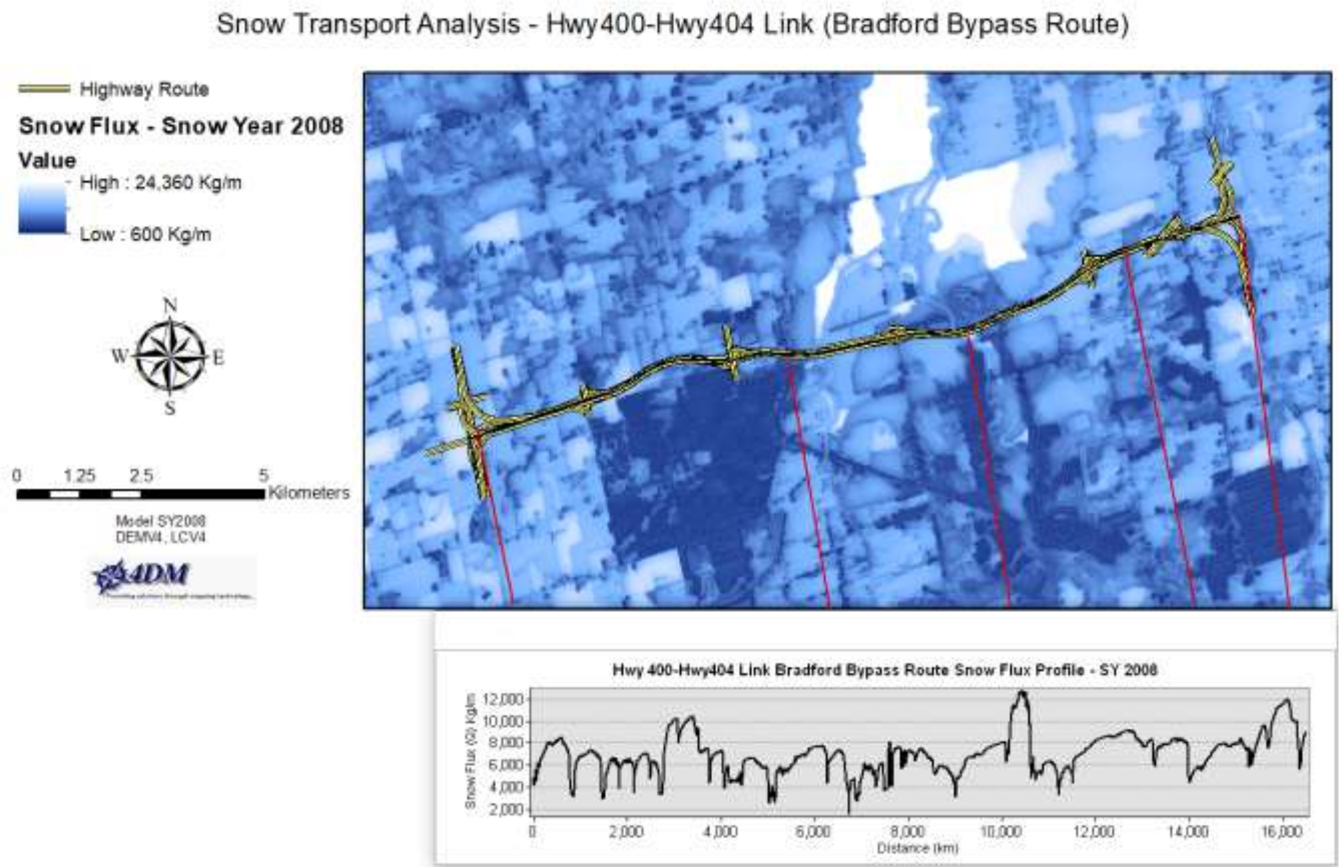

Figure 19 Snow Flux Profiles for 6.6-yr Return Period - 2008 Snow Year

A summary is provided below of the and 6.6-yr SY2008 (**Table 7**) 5-yr SY2006 (**Table 8**) and 2-yr SY2018 (**Table 9**), model results for Q (snowflux) at road segments calculated at Point of Interest (POI) locations (See mitigation section for description for POI).

Table 7 6.6-yr return period (SY2008) Snow Flux Kg/m from SnowStream2D

SY2008 6.6yr	Hwy400_Hwy401 Link	Hwy400	Hwy400 Ramp	10th SDRD	County Rd 4	Bathurst St	2nd Con Rd	Leslie St	Hwy404 Ramp	Hwy404
Max	12,690	7,439	10,933	8,521	7,215	5,594	5,015	8,734	11,344	8,496
Min	1,564	4,819	4,243	4,384	3,571	3,810	3,454	4,829	4,679	4,277
Average	6,992	5,806	7,912	6,913	5,772	4,834	4,363	7,277	9,159	6,263

Table 8 5-yr return period (SY2006) Snow Flux Kg/m from SnowStream2D

SY2006 5yr	Hwy400_Hwy404 Link	Hwy400	Hwy400 Ramp	10th SDRD	County Rd 4	Bathurst Street	2nd Con Rd	Leslie Street	Hwy404 Ramp	Hwy404
Max	10,979	5,667	9,918	6,930	5,955	1,658	1,278	6,645	9,421	6,617
Min	120	1,470	1,210	2,808	2,117	708	515	2,398	1,248	661
Average	4,577	3,033	6,087	5,744	4,044	1,259	958	5,589	6,823	3,854

Table 9 2-yr return period (SY2018) Snow Flux Kg/m from SnowStream2D

SY2018 2yr	Hwy400_Hwy404 Link	Hwy400	Hwy400 Ramp	10th SDRD	County Rd 4	Bathurst Street	2nd Con Rd	Leslie St	Hwy404 Ramp	Hwy404
Max	6,865	2,316	5,858	3,139	2,440	338	145	3,205	5,455	3,355
Min	-	422	48	531	629	89	57	619	228	-
Average	2,068	849	3,102	2,425	1,637	175	88	2,379	3,643	1,723

Table 10. shows the percentage change with respect to increase in snow flux based on the 2-yr return period to the 5-yr and 6.6-yr return periods.

Table 10 Percentage change in Snow Year return period from SY2018

% Increase from SY2018 2yr	Hwy400_Hwy401 Link	Hwy400	Hwy400 Ramp	10th SDRD	County Rd 4	Bathurst Street	2nd Con Rd	Leslie St	Hwy404 Ramp	Hwy404
SY2006 5yr	60%	145%	69%	121%	144%	391%	780%	107%	73%	97%
SY2008 6.6yr	85%	221%	87%	171%	196%	1555%	3351%	172%	108%	153%

The 5yr return period (SY2006) was used as the representative climate conditions for snow mitigation measures along the highway route and interchanges. It provides protection for frequent snowdrift events and more extreme periods where the percentage increases range from 60% to 85% along the highway route. Most locations have a considerable increase in snow flux during extreme events. Details of the mitigation process are described in the next section using SY2006 model results.

8. Mitigation

In this section, the mitigation measures were located along the highway route and at interchanges to minimize future snowdrifting conditions using SY2006 snow accumulation season. Snowdrift mitigation is focused on preventing snow that has already fallen in the surrounding fetch area from being transported onto the road from the predominant wind direction. A Point of Interest (POI) file was created at 25m intervals along the highway route and interchanges consisting of Hwy 400, 10th Sideroad, Bathurst Street, County Road 4, 2nd Concession Road, Leslie Street and Hwy 404. A sample POI distribution over SY2006 snow flux map is shown in **Figure 20** below.

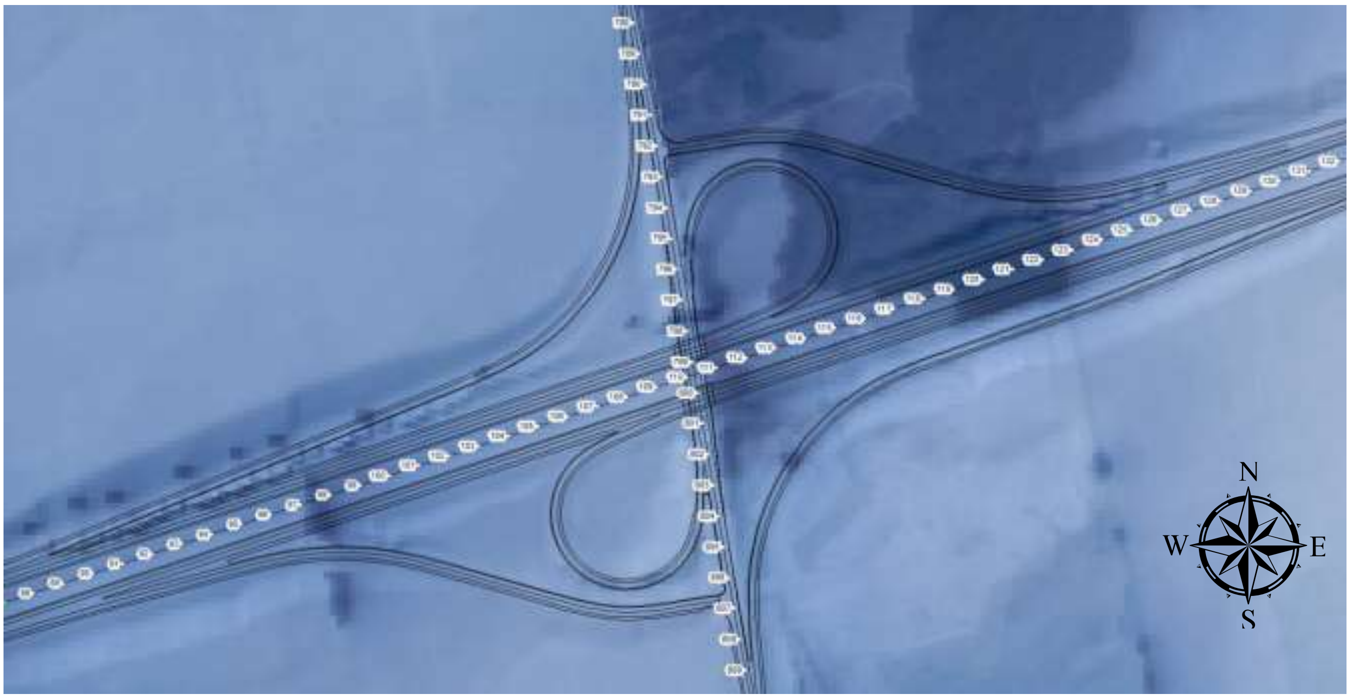

Figure 20 Example of Point of Interest (POI) distribution along the highway route and Interchange at 25m

Next, the SnowStream2D mitigation model was used to conduct the hemispherical calculation of the cumulative snow flux (Qout) at each POI point on one side and then on the other side of the road. Qout is the reduction in snow flux from the mitigation treatment in kg/m. The calculation is based on the azimuth orientation of the road. The mitigation model was initially setup and executed without any treatment to calculate Qout(north), Qout(south), Qout(West) and Qout(East). **Figure 21**, shows the hemispherical snow flux profile along the highway route for both sides of the road.

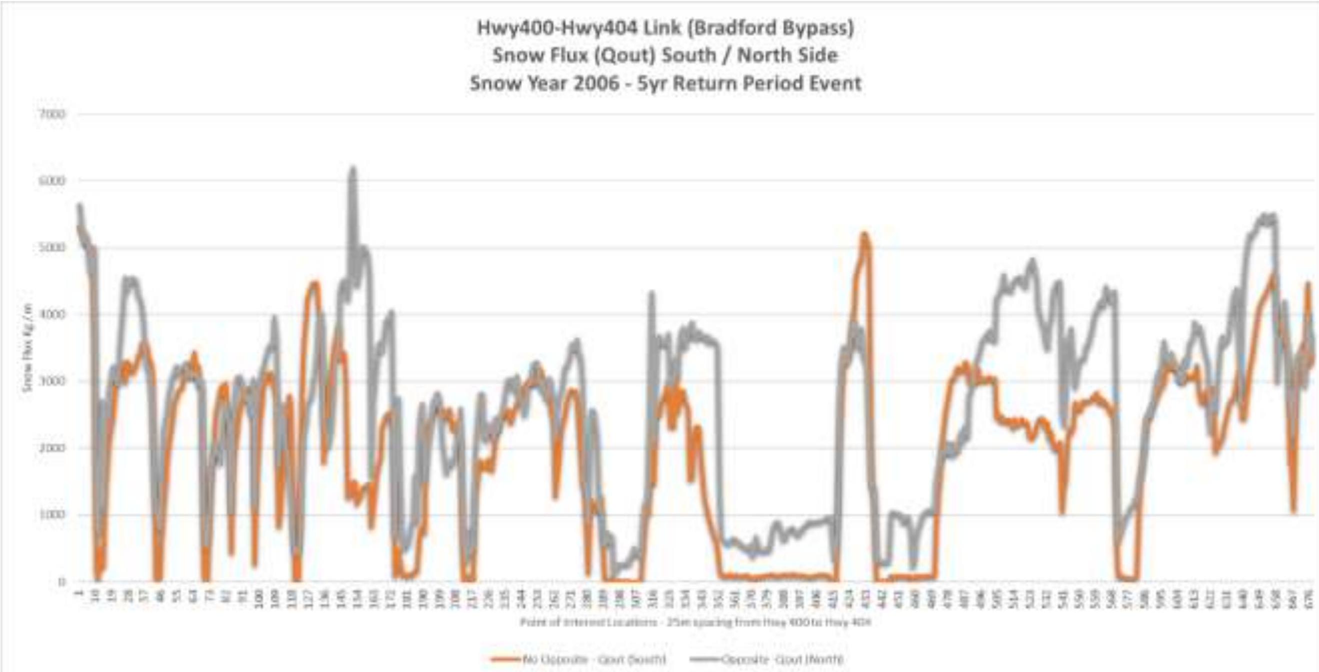

Figure 21 Hemispherical snow flux (Qout) profile along highway route for south and north side

The profile provides a visual location of variability in snow flux locations along the highway route. The quantity of snow flux on north side of the highway route is about 24% greater on average than on the adjacent southern side. This aligns with the calculated PST values, where the main contribution is WNW to NNW. **Table 11** shows statistical values from the POI along the highway route for the north and south side. The maximum snow flux on the north side is 6,196 kg/m. About 49% of the north side and 25% on the south side of the highway route is exposed to 3,000 kg/m and greater, which is suitable for applying the mitigation treatment.

Table 11 Statistical value of snow flux (Qout) on north and south side of the highway route

Statistics SY2006	Qout-(South)	Qout-(North)	Qout(north)-Qout(south) Difference
Average	2,002	2,639	636
Median	2,385	2,869	484
Maximum	5,313	6,196	883
Minimum	-	120	120
STDEV	1,353	1,394	41
Count > 3,000 Kg/m	158	316	158
Count > 4,000 Kg/m	37	106	69
Count > 5,000 Kg/m	11	28	17

The reduction in snowdrifting along the highway route is achieved through mitigation treatments trapping snow. Options include temporary snow fences, snow ditches, and living fences in the form of trees and shrubs. Mitigation treatments are designed to break and slow down the wind but not stop it. The implementation of mitigation treatments consists of factors such as set back distance, orientation, height, and porosity. For this study, the mitigation treatment focused on parallel living fences based on the attack angle. The attack angle is the orientation of highways to the dominate wind direction. Temporary snow fences and snow ditches were not considered because of the long-term costs of installing/removing and replacing the snow fences. Snow ditches can create roadside hazards. Furthermore, the amount of snow flux does not warrant a snow ditch which is typically used in areas of high snowdrifting. Living fences provide cost effective treatment, creates an aesthetic landscape, supports the reduction of greenhouse gases as well as the reduction of winter maintenance/de-icing materials.

Snow mitigation analysis conducted was to identify site specific locations along highway route and at the interchanges for the living fences. The locations were determined by climate analysis using Egbert ECCC station, by calculating the PST magnitude and direction, by executing the SnowStream2D model (calculating snow flux Q kg/m), and then by conducting the SnowStream2D Mitigation model to determine the snow flux Qout for the north/south and west/east sides of the highway route and interchange roads. Finally, visual interpretation was conducted using aerial imagery and the modified right of way DEM (provided by AECOM). The results of prelimary locations are shown below in **Figure 22**. The locations have associated treatment numbers.

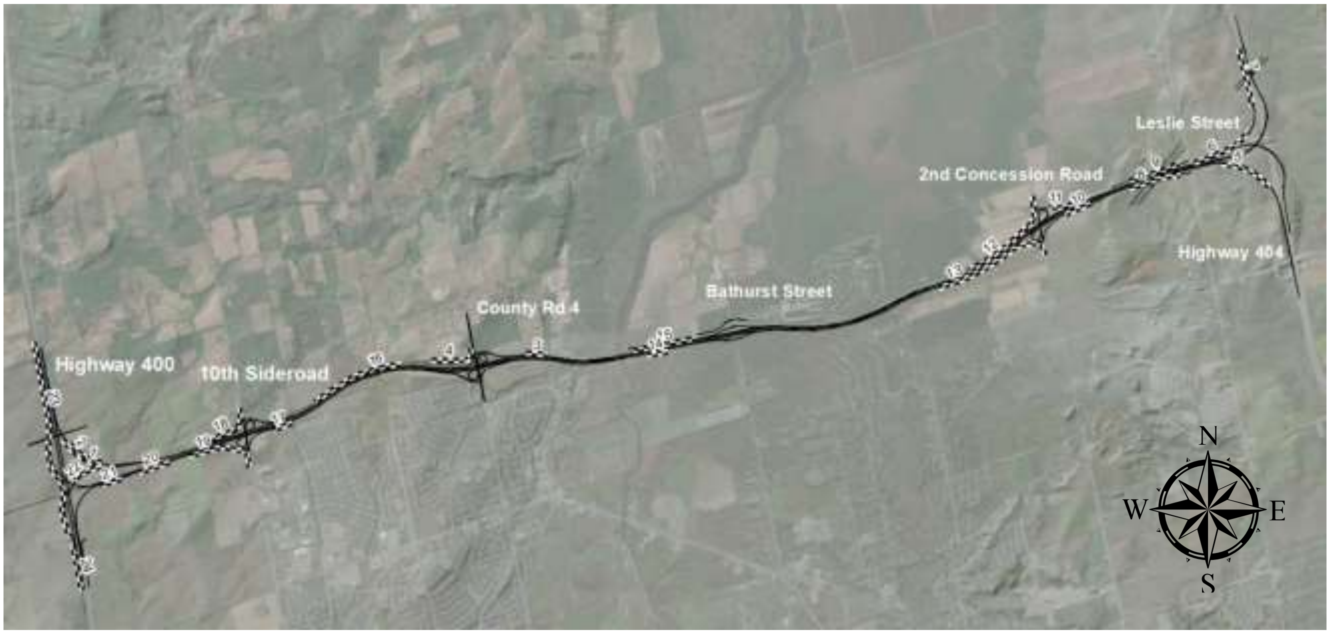

Figure 22 Snow mitigation treatment locations based SY2006 SnowStream2D snow flux model

Sectional images below provide site-specific treatment views with the ROW (orange) in **Figure 23 to 25**.

Figure 23 Mitigation treatment - Highway 400 to east of 10th Sideroad

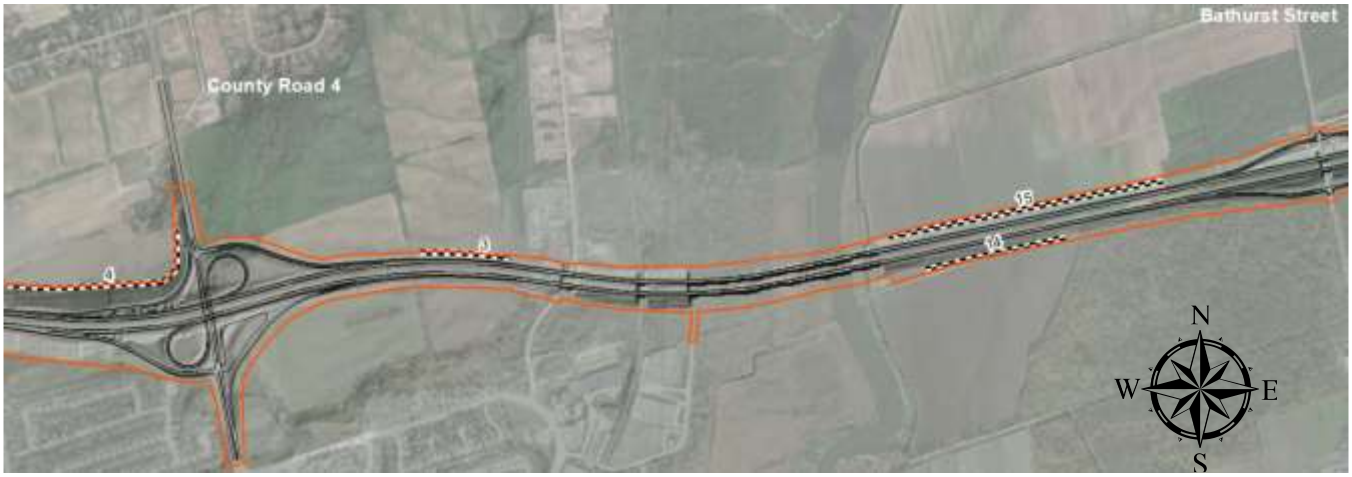

Figure 24 Mitigation treatment – County Road 4 to Bathurst Street

Figure 25 Mitigation treatment – 2nd Concession Road to Highway 404

The mitigation lengths and UTM zone 17 coordinates for the start and end points are provided in **Table 12**.

Table 12 Snow mitigation treatments location and length

Location	Description	Length(m)	UTMZ17 Start X	UTMZ17 Start Y	UTMZ17 End X	UTMZ17 End Y
1	BBP-Hwy400 North Ramp: East-North	587	4886510	609141	609608	4886170
2	BBP-Hwy400 North Ramp: East-South	528	4886470	609236	609677	4886210
3	County Rd 4 Area: East-North	270	4887610	615102	615371	4887590
4	County Rd 4 Area: West-North	629	4887510	613884	614381	4887680
5	BBP-Hwy404 South Ramp: West-South	750	4890030	624020	624658	4889700
6	Hwy404-BBP South Ramp: West-North	874	4890480	624384	623636	4890070
7	Hwy404-BBP South Ramp: West	786	4891510	624236	624363	4890750
8	Hydro One Line: South	671	4889710	622854	623500	4889890
9	Hydro One Line: North	654	4889820	622837	623449	4890050
10	2nd Concession Rd: East-South	374	4889500	622363	622017	4889360
11	2nd Concession Rd: East-North	520	4889620	622310	621811	4889500
12	2nd Concession Rd: West-North	1333	4889630	621579	620773	4888670
13	2nd Concession Rd: West -South	1621	4888440	620395	621756	4888870
14	Bathurst Street Area: West-North	422	4887650	617007	616595	4887560
15	Bathurst Street Area: West-South	825	4887820	617295	616487	4887660
16	10th Sideroad-County Rd 4: North	1235	4887470	613492	612378	4886990
17	10th Sideroad Area: East-South	311	4886720	612087	611802	4886590
18	10th Sideroad Area: West-North	815	4886910	611423	610880	4886440
19	10th Sideroad Area: West-South	975	4886290	610765	611560	4886150
20	Hwy 400-BBP West Ramp: East-South	433	4886200	610521	610110	4886060
21	Hwy 400-BBP Join: East-South	291	4886000	609926	609647	4885920
22	BBP-Hwy 400 Ramp: East-North	378	4886150	609636	609303	4885990
23	Hwy 400-BPP Ramps: West-North	2489	4887660	608776	609240	4885260
24	BBP-Hwy 400 South Ramp: West-South	610	4885170	609267	609388	4884570

A total length of recommended mitigation for highway route, ramps and intersection is 18,380 m

The determination of the offset distance from the pavement edge to the treatment was done by applying SnowStream2D mitigation model to estimate the reduction of snow flux passing through a living fence. The model calculates the drift length of the captured snow and Qout. The treatment scenarios that were models along the highway route consist of the following:

- A simulated planting of 0.75m shrubs to maximum growth of 0.3m per year to maximum height of 2m with 50% porosity.
- A simulated planting of 0.75m shrubs to maximum growth of 0.3m per year to maximum height of 5m with 50% porosity.
- A simulated planting of 2m tree to maximum growth of 0.3m per year to maximum height of 15m with height/weight ratio with 50% porosity.

4DM

The SnowStream2D mitigation model was applied for SY2006 conditions for the three mitigation treatments. The statistical results of the effectiveness of the mitigation treatment along the highway route in shown in **Table 13**.

Table 13 Snow Mitigation of 2m Shrub Hwy400-Hwy404 Link for snow flux Qout (kg/m)

	Q (North)	Q(South)	Qout (North)	Drift Length (m)	Mitigation Reduction	Qout (South)	Drift Length (m)	Mitigation Reduction
Average	2,639	2,002	1,452	5	54%	1,204	3	52%
Median	2,869	2,385	1,514	6	48%	1,364	4	42%
Maximum	6,196	5,313	4,608	9	84%	3,930	7	85%
Minimum	120	0	22	0	26%	22	0	26%
STDEV	1,394	1,353	1,041	3		937	2	

Table 14 Snow Mitigation of 5m Shrub Hwy400-Hwy404 Link for snow flux Qout (kg/m)

	Q (North)	Q(South)	Qout (North)	Drift Length (m)	Mitigation Reduction	Qout (South)	Drift Length (m)	Mitigation Reduction
Average	2,639	2,002	1,233	6	59%	1,023	4	57%
Median	2,869	2,385	1,199	7	52%	1,183	5	51%
Maximum	6,196	5,313	4,006	10	85%	3,417	8	86%
Minimum	120	0	22	0	26%	0	0	26%
STDEV	1,394	1,353	1,016	3		937	2	

Table 15 Snow Mitigation of 15m Tree Hwy400-Hwy404 Link for snow flux Qout (kg/m)

	Q (North)	Q(South)	Qout (North)	Drift Length (m)	Mitigation Reduction	Qout (South)	Drift Length (m)	Mitigation Reduction
Average	2,639	2,002	348	16	87%	316	16	86%
Median	2,869	2,385	356	16	88%	323	16	87%
Maximum	6,196	5,313	1,072	17	89%	1077	17	89%
Minimum	120	0	15	0	76%	0	0	72%
STDEV	1,394	1,353.47	210	2		249	2	

The expected maximum snowdrift length and treatment is provided below:

Single Row Shrubs

- 2m Shrub north side = 9m drift length
- 2m Shrub south side = 7m drift length
- Average of snow flux reduction from mitigation treatment = 52% - 85%
- Recommended minimum setup back = 12m > from edge of the shoulder for all treatment locations.

Single Row Shrubs

- 5m Shrub north side = 10m drift length
- 5m Shrub south side = 8m drift length
- Average of snow flux reduction from mitigation treatment = 52%-86% reduction
- Recommended minimum setup back = 12m > from edge of the shoulder for all treatment locations.

Single Row Tree

- 15m Tree north side = 17m drift length
- 15m Tree south side = 13m drift length
- Average of snow flux reduction from mitigation treatment = 72%- 80% reduction
- Recommended minimum setup back = 19m > from edge of the shoulder

If using mix of shrubs and trees or double row shrubs, it recommended to place at 19m> for all treatment locations as a minimum.

9. Recommendations

The climate analysis, PST and SnowStream2 modeling, along with visual interpretation, has identified preliminary selected areas for snow mitigation treatment along the highway route and interchanges. Snow flux modeling quantifies the cumulative snow transport coming into the highway from the adjacent land from all directions to mitigate snowdrifting onto the road. The locations and lengths of treatments have been provided in this report assuming an ultimate 8 lane design. Should the project footprint change in future and at the Detail Design stages the snow drift modelling and areas proposed for mitigation are to be reviewed and confirmed.

The identification of treatments was based on climate parameters, current land cover and topographic data for the modeling area. The preliminary snowdrift mitigation results were provided to Landscape, Terrestrial Ecosystems and any other teams that may be impacted by the locations proposed for snowdrift mitigation from wholistic perspective. A preliminary terrain modification for the highway route was incorporated into the analysis. Snowdrift exposure is considered moderate to low along the highway route with maximum predicted snow flux of 6,196 kg/m for SY2006, representing a 5-yr return period. SY2006 was used as the representative snowdrift year for mitigation because the return period is reasonable occurrence of more intense snow flux than commonly occurrence event. The assessment approach leads to robust snowdrift protection along the highway route. The type of snow mitigation treatment recommended for this area should be living fences of shrubs, trees, or a mixture. The following is a list of recommendations:

- Living fence should consist of coniferous shrub/hedges with 50%-60% porosity, a minimum 2m height and a minimum set back of 12m from the edge of shoulder for all locations identified in the maps. It is possible to also use deciduous species intermixed with a 50%-60% porosity in winter periods. Depending on soil conditions and salt tolerance, examples could be Nannyberry and Hornbeam plants.

Figure 26 Nannyberry and Hornbeam plants

- Increasing the height and doubling the planting shrubs is beneficial to reducing the snow flux. Double planting increases coverage for plants that may die off or grow at different rates. Offset planting should be used and a minimum setback distance of 19m from shoulder pavement edge applied and comply with MTO regulation for sight lines.

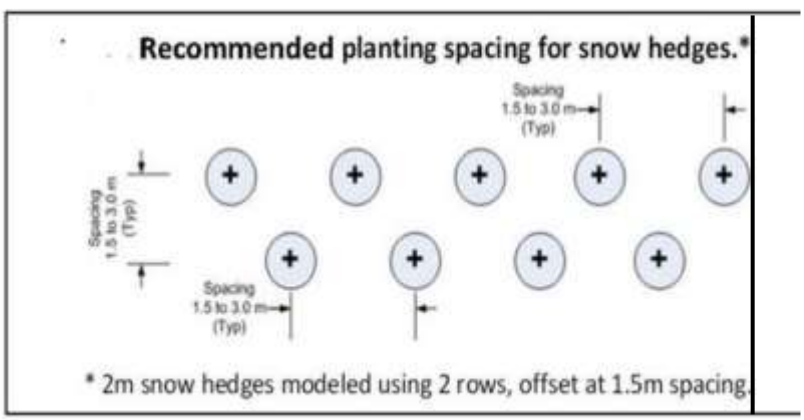

Figure 27 Planting arrangement for double row shrubs

- A single row of trees can be used as mitigation treatments but should be placed at minimum setback of 19m from the edge of the shoulder and comply with MTO regulation for sight lines. Conifer species is recommended for snowdrifting mitigation; however, deciduous planting can be applied if the 50%-60% porosity is achieved during the winter.

Figure 28 Conifer trees snow fence

- Where possible place mitigation strategy based on 5-yr return event or 20% probability of exceedance in any given year near/at the ROW property boundary to provide additional buffer for snowdrift length during extreme Snow Accumulation Seasons.
- In placing mitigation treatment in the corridor, some locations were identified to have a reduce footprint based on the preliminary mapping data between the edge of pavement and the ROW limits. During detail design the footprint should be verified and confirmed. Mitigation treatments are recommended to be placed in all of these locations. For distances less than 12m, treatment should use heights that are less than 2m and porosity closer to 60%. The specific height will be based on confirmed distance during the Detail Design phase The list below are the narrow locations identified.
    - Treatment 21 (BBP eastbound on ramp) portion is approximately 14m from the pavement edge for about 30m
    - Treatment 2 (Hwy400 northbound exit ramp) portion is approximately 9-12m from the pavement edge for about 30m
    - Treatment 18 (10th Sideroad southbound onramp) portion is approximately 9-12m from the pavement edge for about 50m
    - Treatment 19 (10th Sideroad southbound exit ramp) is approximately 13m from the pavement edge for about 10m
    - Treatment 12 (2nd Concession Road southbound on ramp) is approximately 11-13m from the pavement edge for about 65m
    - Treatment 13 (2nd Concession Road southbound exit ramp) is approximately 10-13m from the pavement edge for about 80m

- In general, it is possible that any of the mitigation treatment applied, can result in the snow captured by the fence encroach onto paved areas in servere snow accumulation seasons. Snowdrift mitigation is a balanced risk-based approach that considers technical and practical factors; therefore, it is not possible to mitigate for all scenarios. There are additional strategies or options that can be considered to further enhance mitigation measures to compliment the living fences that include:

- Enhance pavement markers, signage, ramp speed warning can improve drive awareness during more extreme conditions in the narrow area.
- Monitoring and increased roadside maintenance will be required in more extreme years.
- MTO purchasing additional lands adjacent to the ROW, in narrower areas to accommodate enhancements.
- Coordinate/negotiate with farmers to leave narrow swath of crop residue.
- Explore additional treatments between the mitigation and road such as low plantings to hold the snow in place.
- Adjust mitigation treatment design during the detail design phase such as lowering the living fence height and increase the porosity to shorten the snow capture length.

During subsequent Detail Design phases, the Landscape Plan shall be referenced as it provides levels of recommended mitigation to aid in addressing the narrow locations flagged in this Report. Final details and recommendations shall be confirmed in subsequent Detail Design phases for both the Snowdrift and Landscaping Reports and considered from a holistic perspective.

- On going monitoring of mitigation measures is highly recommended to determine if treatments should be lengthening and adjusted such as height and setback as part of highway maintenance. Monitoring should also continue as part operational maintenance to adjust living fences as needed.

In addition to mitigation treatments, to improve driver awareness of hazard conditions, other strategic measures could be considered to improve driver awareness of snowdrifting conditions. Although high priority areas have been identified, the highway route will still be exposed to snow flux. These measures consist of the following:

- Implementing dynamic variable messaging boards of changing road and environment conditions. Based on the Road Weather Information System, snow on ground and wind conditions can be used to inform drivers of the potential snowdrifting conditions through the messaging boards.
- Using sensor technology that includes meteorological, pavement and snow particle sensors for snow drifting measurements for warning of changing condition. A snow flux sensor placed on the north side of the road can be used to quantify the severity of snowdrifting conditions. An example of a snowflux sensor is shown in **Figure 29**.

Figure 29 Snow particle sensor

- High resolution Numerical Weather Prediction (NWP) data from Environment and Climate Change Canada and National Oceanic Atmosphere Administration can provide forecasted wind, temperature, and precipitation conditions for snowdrift prediction. Data resolution for the High Resolution Deterministic Prediction System is 2.5km. **Figure 30** shows winter precipitation data from Environment Climate Change Canada GEM model heading towards Ontario. The data can provide advanced warning of PST and predicting snowdrift conditions as shown in **Figure 31**.

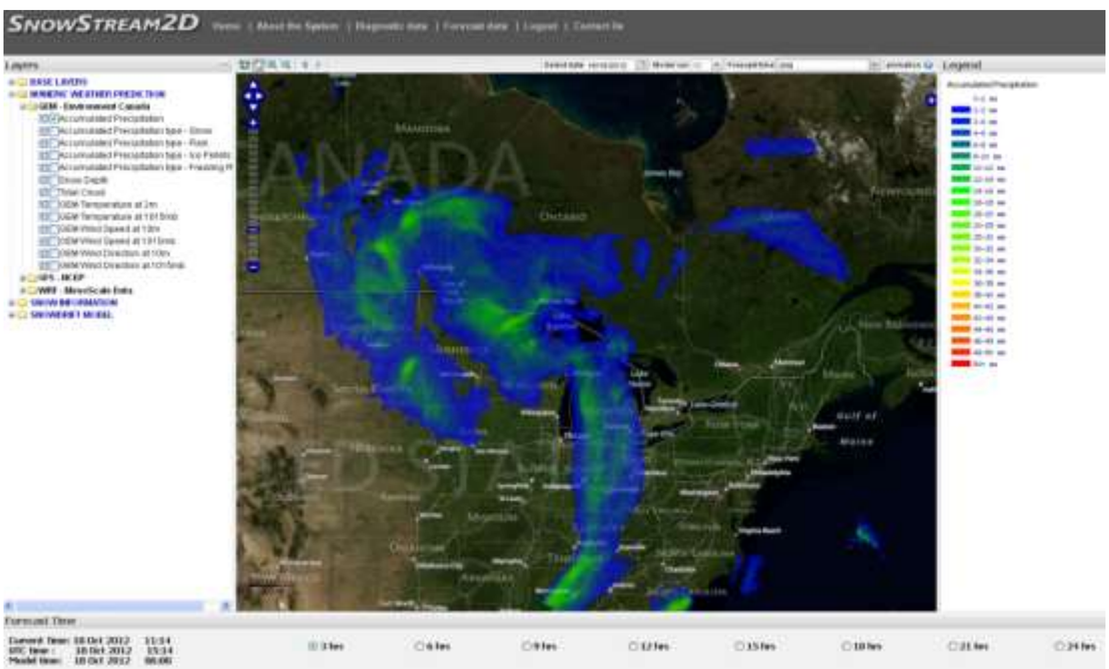

Figure 30 Example of precipitation from NWP data

Figure 31 shows example on SnowStream2D predicting snowdrifting conditions based on snow on ground, forecast winds and temperature on Highway 400. Red area represents area of snowdrift locations.

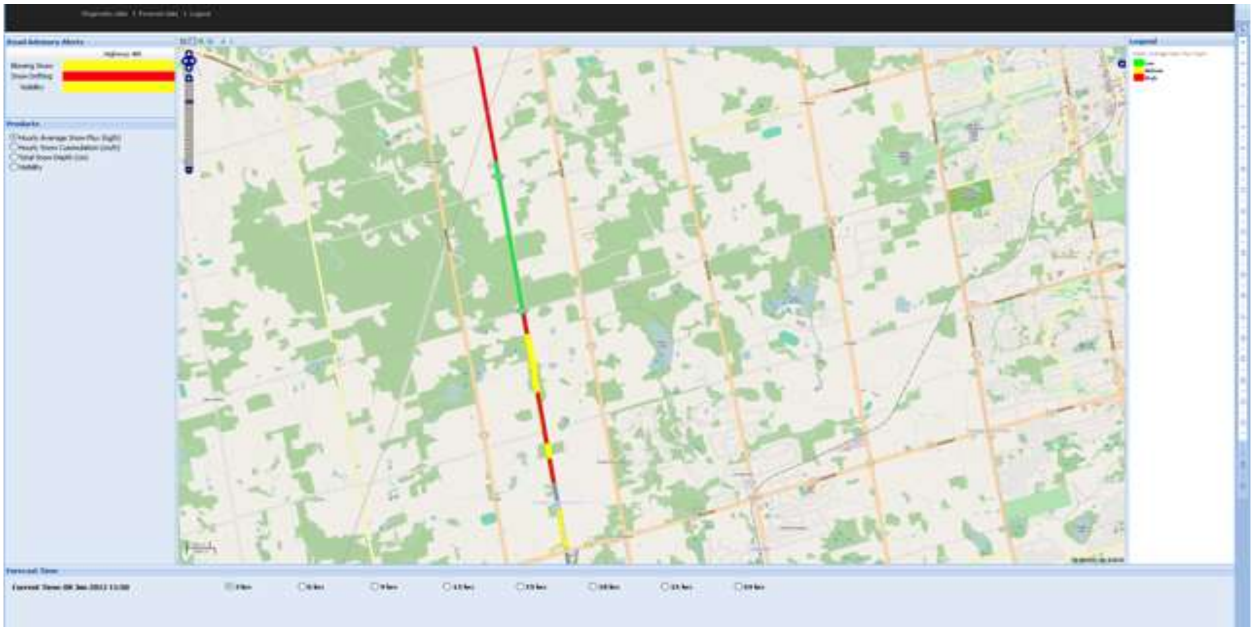

Figure 31 Forecast snowdrifting on Highway 400

- At strategic locations on the highway route, place signs of the potential risk of snowdrifting to provide further driver awareness of potential adverse conditions.

Figure 32 Snowdrift sign

- Placing road delineation poles in snowdrift areas for providing increased visibility of pavement edges in snowdrift locations.

Figure 33 Pavement edge marker with reflector

- Implement variable speed signage as a "recommend" or "advisory" based on weather and road conditions. Speed recommendation would be between maximum and minimum speed. Signs are electronic and dynamic, link to the dynamic messaging boards, and are posted at all the interchanges. Speed adjustment could be done manually or based on sensing in-situ conditions that include fog, severe precipitation and snowdrifting conditions. An example of signage for variable speed is shown in **Figure 34**.

Figure 34 Variable speed signage

10. Summary of Environmental Commitments

Preliminary Design Commitments

Impacts to snowdrift and proposed mitigation measures, monitoring activities and commitments identified during this snowdrifting assessment are summarized in **Table 16** below.

Table 16 Summary of Preliminary Design Environmental Concerns and Commitments

ID	Issues / Concerns / Potential Effects	Concerned Agencies	ID	Mitigation, Protection, Monitoring, and Commitments
SNOW-1.00	Drifting snow on highway from wind drive events causing winter road hazard	Ministry of Transportation,	SNOW-1.01	Snow mitigation treatment recommended for this area should be living fences of shrubs, trees, or a mixture. Living fence should consist of coniferous shrub/hedges with 50%-60% porosity, a minimum 2m height and a minimum set back of 12m from the edge of shoulder for all locations identified in the maps. It is possible to also use deciduous species intermixed with a 50% porosity in winter periods. Depending on soil conditions and salt tolerance, examples could be Nannyberry and Hornbeam plants Alternatively A single row of trees can be used as mitigation treatments but should be placed 19m from the edge of the shoulder and comply with MTO regulation for sight lines. Conifer species is recommended for snowdrifting mitigation; however, deciduous planting can be applied if the 50%-60% porosity is achieved during the winter Please see report for specifics
			SNOW-1.02	Monitoring and road maintenance are required for checking the effective of the treatment. Living fences should be adjusted accordingly in terms of die off, extending location and checking porosity/height
SNOW-2.00	Living fences will mitigate a portion of snow drifting, other measures can be implemented to provide improve driver awareness	Ministry of Transportation,	SNOW-2.01	Implement dynamic messaging boards for winter hazard conditions
			SNOW-2.02	Using sensor technology that includes meteorological, pavement and snow particle sensors for snow drifting measurements for

ID	Issues / Concerns / Potential Effects	Concerned Agencies	ID	Mitigation, Protection, Monitoring, and Commitments
				warning of changing condition during snow storms and wind drive events.
			SNOW-2.03	Implement high resolution Numerical Weather Prediction (NWP) data from Environment and Climate Change Canada and National Oceanic Atmosphere Administration to provide forecasted wind, temperature, and precipitation conditions for snowdrift prediction.
			SNOW-2.04	At strategic locations on the highway route, place signs of the potential risk of snowdrifting to provide further driver awareness of potential adverse conditions.
			SNOW-2.05	Placing road delineation poles in snowdrift areas for providing increased visibility of pavement edges in snowdrift locations.
			SNOW-2.06	Implement variable speed signage as a “recommend” or “advisory” based on weather and road conditions

Appendix A - Quality Review

Quality control measures implemented in this project involved a review of meteorological data for gaps in the hourly and daily observations. A data review of daily snow on ground was conducted and a process for addressing gaps were implemented. For hourly data, analysis of missing records was conducted. Only negligible amount of missing data was identified. 4DM also review previous projects in the area to assess if results were consistent.

Snow flux model input data requires the classification land cover. Available data was retrieved from Land Information Ontario and Agriculture and Agrifood Canada. A Sentinel 2 images over the model area was acquired in July 2022 to provide current observed land cover information to verify any changes from data of the model area. Digitized land cover data was checked against most current land cover data.

DEM data from LiDAR data set was resampled and merged from two sources. Then the modified DEM in the ROW was then embedded into model area DEM. I review of DEM was conducted for spikes, depressions, holes, seams, and artifacts. In addition, coordinate reference systems were checked for alignment of the LiDAR data with land cover using same projection and datum.

SnowStream2D modeling was checked for data abnormalities and model errors. A review of output was checked against the PST magnitude and then model results were reviewed for consistent across the model area. A check on past project was also conducted to see if the magnitude of snowdrift was consistent. Results from SnowStream2D mitigation model was also reviewed abnormal values in Qout results and drift lengths based on POI locations.

Review process involved 4DM modeling team of four technical members. Individual team member not involved in the processing steps were assigned to review the data.

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