Effective Windbreak Design to Control Soil Loss by Wind Erosion in the Nottawasaga Valley Watershed

April 2, 2013

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Photo by Kristina Vasiljevic (NVCA Watershed, October 29, 2012)

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RE: Effective Windbreak Design to Control Soil Loss by Wind Erosion in the Nottawasaga Valley Watershed

Dear Mr. Post,

Please accept our final report entitled "Effective Windbreak Design to Control Soil Loss by Wind Erosion in the Nottawasaga Valley Watershed." This final report was prepared for the Nottawasaga Valley Conservation Authority (NVCA) with the aim of characterizing the factors influencing wind erosion and recommending windbreak orientation and management that will effectively mitigate wind erosion of soil in the NVCA watershed area.

Our educational backgrounds in environmental sciences, data analysis and environmental management make this group capable of accurately recommending strategies and approaches to reduce wind erosion through the use of windbreak systems. This final report includes: an introduction to the soil erosion problem in the NVCA watershed, background information regarding the problem and area of interest, a literature review focused on the physical conditions influencing wind erosion (including both soil and wind properties), the goals and objectives of the report, methods and materials for this study, the results of all analyses, a discussion of the results, recommendations for windbreak orientation and placement, possible future directions and conclusions.

The components of this final report provide recommendations for windbreak location, orientation and management to reduce soil erosion in the NVCA watershed.

Please feel free to contact us with regard to any questions that you may have,

Heather Alp, Elizabeth Cowan, Julia De Vito, Kristina Vasiljevic, Sophie Volhard and Catherine Wisniowski

Acknowledgements

We would like to extend our sincere appreciation to Ryan Post from the Nottawasaga Valley Conservation Authority for his ongoing support in guiding our group through the development and challenges of this project. We would also like to thank him for taking the time to give us a tour of the watershed. Our thanks are also extended to our professor Shelley Hunt and our teaching assistant Tara Holland from the University of Guelph, as we appreciate the feedback provided for the various components of the project. Finally, we would like to thank professor Bahram Gharabaghi from the University of Guelph, as well as Kevin McKague and Stewart Sweeney from the Ontario Ministry of Agriculture, Food and Rural Affairs for providing us with insight into the project and offering their expertise on the topic.

Executive Summary

The Nottawasaga Valley watershed is located within Simcoe County in southwestern Ontario. The watershed suffers from severe wind-based erosion of its Tioga series and other sandy loam soils. This erosion is a major contributor to increased phosphorus loading in the surrounding water bodies, which is a concern as it decreases the health of the watershed (LSSAC 2008; Brown et al. 2011). This project provides suggestions for the placement of windbreaks in order to help mitigate soil erosion in the Nottawasaga Valley watershed. Soil type, land cover, and precipitation data were investigated in order to better understand the factors that influence soil erosion in the Lake Simcoe area. The effect of wind-based soil erosion on the Lake Simcoe basin was determined through an extensive literature review. The review included information on many potential influencing factors such as soil particle size, phosphorus loading, moisture content, surface roughness, land-cover type and soil structure. A review was also conducted on the components of the Revised Wind Erosion Equation (RWEQ) to determine the susceptibility of various field conditions to wind erosion. An analysis of soil erosion data was conducted in order to determine which factors influence soil erodibility in the research area and is presented through GIS maps. These maps show that erodibility due to soil type was high in the southeast portion of the watershed, along with a small section in the northeast. Land use has the greatest effect on erodibility in the center region as well as the southeast section of the watershed. Land use may have a larger effect in the southwest region where the area is classified as highly erodible due to both land use and large number of highly erodible soil types. Hourly wind speed and direction data from 2008-2012 were examined in order to create rose diagrams. The rose diagrams showed a predominant wind direction from the NNW. From this, recommendations have been made to place windbreaks in a WSW-ENE direction, making sure to focus on areas most prone to soil erosion as determined in the GIS analysis.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

1.1 Our Group

This project was completed by a group of six fourth year students at the University of Guelph in Guelph, Ontario. It is part of a mandatory 8 month capstone ‘Project in Environmental Sciences’ course (ENVS*4011/4012). We are all students in the Environmental Sciences program with diverse majors including Environmental Biology, Earth and Atmospheric Science, Geography, and Natural Resources Management. Our interests lie in areas of soil science, GIS, meteorology, biology, and ecology. These subjects have been the focus of our degrees at the undergraduate level and have provided a knowledge base for the completion of this project.

1.2 Our Client

This report was prepared for the Nottawasaga Valley Conservation Authority (NVCA) following a proposal by our primary contact Ryan Post. The watershed encompasses 18 municipalities including Adjala-Tosorontio, Amaranth, Barrie, The Blue Mountains, Bradford-West Gwillimbury, Clearview, Collingwood, Essa, Innisfil, Melancthon, Mono, Mulmur, New Tecumseth, Oro-Medonte, Grey Highlands, Shelburne, Springwater and Wasaga Beach. The NVCA is dedicated to the protection of the land and water resources of this 3700 km^2-plus area. One issue that the watershed has been faced with is the loading of phosphorus into Lake Simcoe via wind erosion. Not only does this compromise water quality and create issues for aquatic systems, but the loss of topsoil also degrades valuable farmland. Thus, the NVCA is looking at windbreaks as a potential solution for this issue.

1.3 Project Outline

The NVCA watershed, located west of the Lake Simcoe watershed, consists of several highly valuable agricultural land types which support extensive crop production. The fine-grained soils found here are extremely vulnerable to wind erosion, especially if no crop cover is established. Soil erosion and phosphorus (P) loading in the NVCA watershed is of concern for the continued health and function of the area as it continues to be a major agricultural area. The main focus of this study is to suggest windbreak placement based on analysis of seasonal soil erosion data in the NVCA watershed, including an analysis of the factors that influence the erodibility of soils in the area. Research and data analysis will investigate the qualitative impacts of wind-based soil erosion on the Lake Simcoe basin. Windbreak placement will be determined in relation to the predominant wind directions of the area to most effectively reduce soil erosion. Based on these components, as well an extensive literature review, recommendations will be made for key windbreak locations. The project results are anticipated to be used by the client (the NVCA), by the county and municipalities, and by other corporate partners. Windbreaks, in combination with best management practices, represent a viable option for the mitigation of the potential negative impacts resulting from agricultural land use.

2.0 Background

2.1 Phosphorus Loading in Lake Simcoe

The Lake Simcoe watershed has been subject to human development for over 200 years. Continual increases in urban development and agricultural activities have contributed significantly to erosion and phosphorus (P) loading occurring in the area. Most of the conversion of forested land to agricultural land occurred between 1820 and 1890, however more than 70% of the area's population became established in the 30 years after the mid-1960s. P loading first appeared around 1910 and remained low at 2–3 tonnes per annum until the 1960s, after which loading increased to about 20 tonnes per annum by 1990 as human population expanded (Evans et al. 1996). Today, more than 350,000 people live in the area with growth expected to continue in the future (MOE 2012).

Agricultural, industrial and urban non-point and point sources all release P into the atmosphere, wherein it is transported by wind to other areas. This atmospheric P has the potential to reach soil and water sources by wet and dry deposition processes including rain, sleet, snow, adsorption, and settling (Ramkellawan et al. 2009). The concern is that out of the estimated 53-67 tonnes per annum of P entering Lake Simcoe, atmospheric deposition is believed to contribute anywhere from 16-38 tonnes of this total value (Ramkellawan et al. 2009). The majority of this atmospheric load to Lake Simcoe is due to wind-borne erosion of agricultural soils to the north and west of the watershed (LSSAC 2008; Brown et al. 2011). This area includes NVCA lands dominated by loam soils and associated high value agricultural land. It is imperative to identify sources from which P is emitted and to implement effective methods to help improve water quality (Brown et al. 2011).

Current legislation focuses on P load reduction with the goal of improving water quality and the long-term health of the watershed while still providing water to residents. This is done partly through the Lake Simcoe Protection Plan, which provides guidelines for continued monitoring of the watershed and facilitating sustainable growth in the area (Government of Ontario 2009). The Government of Ontario (2009) reported that the extensive research, monitoring and scientific studies conducted in the four years prior to 2009 have shown a link between human-related activities and the declining health of the Lake Simcoe watershed. These activities include urban recreational and rural agricultural practices (Government of Ontario 2009). Numerous studies worldwide have identified P as a limiting nutrient for both terrestrial and aquatic ecosystems (Anderson and Downing 2006).

Further research and exploration in methods preventing P loading into the Lake Simcoe watershed is warranted. Although many stewardship programs are in effect for the area, the public remains uninformed, which creates the impression that little progress is being made. This is partly due to the poor measurement of spatial variability of deposition rates, which can help locate 'hot spots' of P loading from anthropogenic activities (Brown et al. 2011). Despite the number of programs in place, the measurement and determination of P sources remains a challenge (Brown et al. 2011).

2.2 Location of Study Site

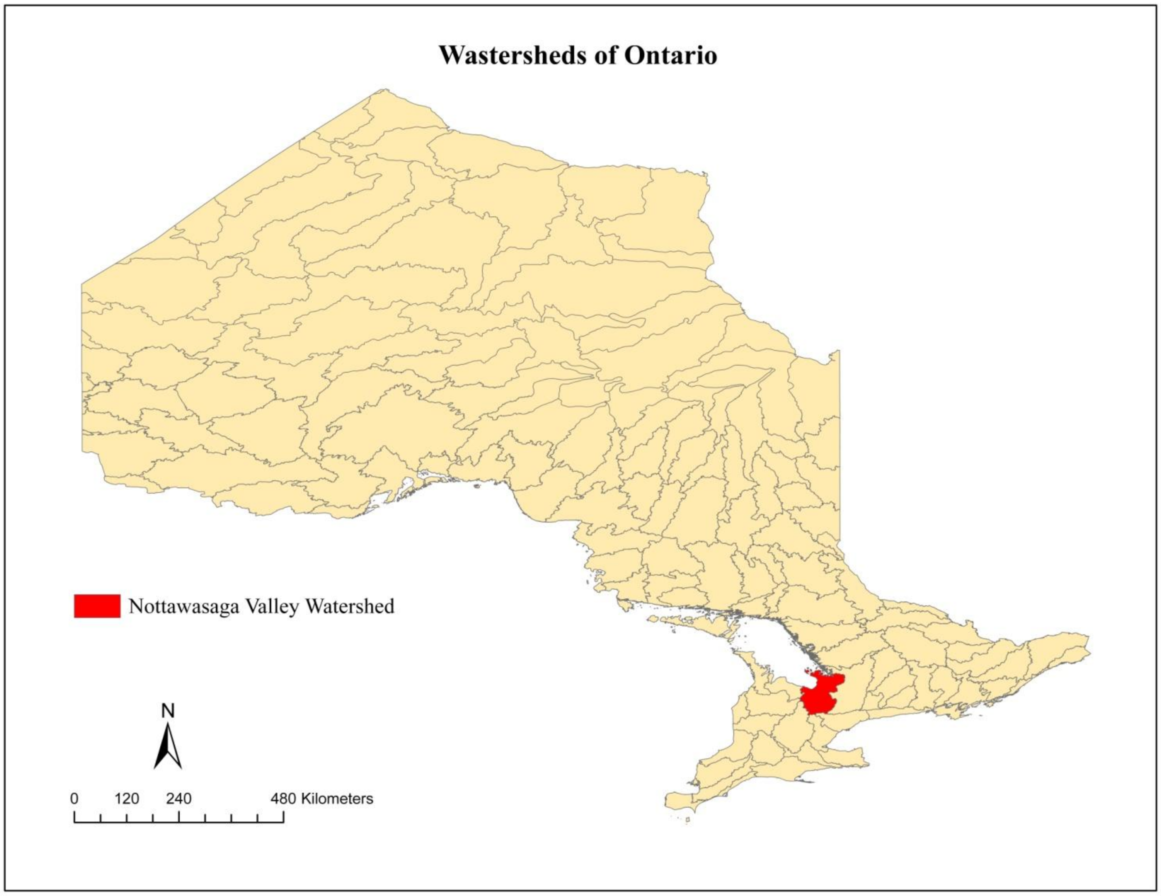

Figure 2.1: A representation of the Nottawasaga Valley watershed within Ontario.

2.3 NVCA Watershed

Located in south-central Ontario, the Nottawasaga Valley watershed has a large geographical range and is characterized by four regional-scale physiographic regions, including the Horseshoe Moraines, Peterborough Drumlin Field, Simcoe Lowlands and Simcoe Uplands (SPC 2011; NVCA/OMAFRA 2012). The vast majority of the watershed (74%) is located in Simcoe County, with the remainder located in Dufferin County (22%) and Grey County (4%) (SPC 2011). According to the South Georgian Bay-Lake Simcoe Source Protection Committee (2011), the Nottawasaga Valley watershed borders Georgian Bay in the north, the Niagara Escarpment (and Grand, Grey Sauble and Saugeen watersheds) to the west, the Humber and Credit River watersheds to the south and the Lake Simcoe watershed to the east. These boundaries form the Nottawasaga Valley Source Protection Area as well as the limits of the Nottawasaga Valley Conservation Authority (LSRCA 2013). As demonstrated by Figure 2.2, the Nottawasaga Valley watershed is composed of ten subwatersheds including: Upper Nottawasaga River, Mid Nottawasaga River, Lower Nottawasaga River, Boyne River, Innisfil Creek, Pine River, Willow Creek, Blue Mountains, Mad River, and Severn Sound Headwaters (NVCA 2007a).

Table 2.1: Drainage areas of subwatersheds within the Nottawasaga Valley watershed (SPC 2011).

Subwatershed	**Drainage Area (km^2)**
Upper Nottawasaga River	338.136
Lower Nottawasaga River	455.43
Blue Mountains	220.72
Innisfil Creek	490.03
Boyne River	239.94
Mad River	451.94
Willow Creek	306.53
Middle Nottawasauga River	296.78
Total Area	3147 km^2

This watershed's vast drainage area of about 3,147 km^2 is predominantly covered with natural vegetation (1,086 km2 or 34.5% of total area), generally healthy forest (about 22.5% of total area) and significant expanses of wetlands (about 12% of total area) (LRSCA 2013). With over 181,000 people living in the Nottawasaga Valley watershed, there exist numerous city centers of high population density in the area (i.e. Collingwood, Wasaga Beach). However, there are also many areas that are predominantly agricultural communities (SPC 2011). Thus, the human geography varies greatly across the watershed (LSRCA 2013). Within this vast area there is a single surface water intake (located at Collingwood) and 107 municipal wells that serve as the infrastructure for the area’s 35 drinking water systems (LSRCA 2013).

Figure 2.2: Physiography of the Nottawasaga Valley watershed highlighting the ten subwatersheds and the major watercourses.

2.4 General Site Description

2.4.1 Geology

Knowledge of the geology underlying a watershed is the key to understanding groundwater and surface water processes as well as their interactions. The type of bedrock present will dictate the sediments and soils occurring within an area. This will influence several factors including (but not limited to) how and where groundwater will flow, how actively materials will move within the watershed, as well as how vulnerable the aquifer may be to various contaminants (MOE 2012). In terms of geology, the Nottawasaga Valley watershed bedrock is between 300 and 400 million years old and is overlain with formations such as the Lorraine, Queenston, Black River, and Trenton formations, that are apparent in outcrops such as the Niagara Escarpment (NVCA 2005). The watershed's basin is composed of this Paleozoic and Precambrian bedrock, which is now covered with unconsolidated overburden that was deposited during the Quaternary Period (LSRCA 2013). This overburden consists of glacial till, gravel, sand or clay in most areas of the valley (NVCA 2005). Specifically, the Paleozoic bedrock within the Lake Simcoe area consists of carbonate and siliciclastic sedimentary rocks originating in the Middle Ordovician (Blackriveran to Trentonian) age (Armstrong 2000).

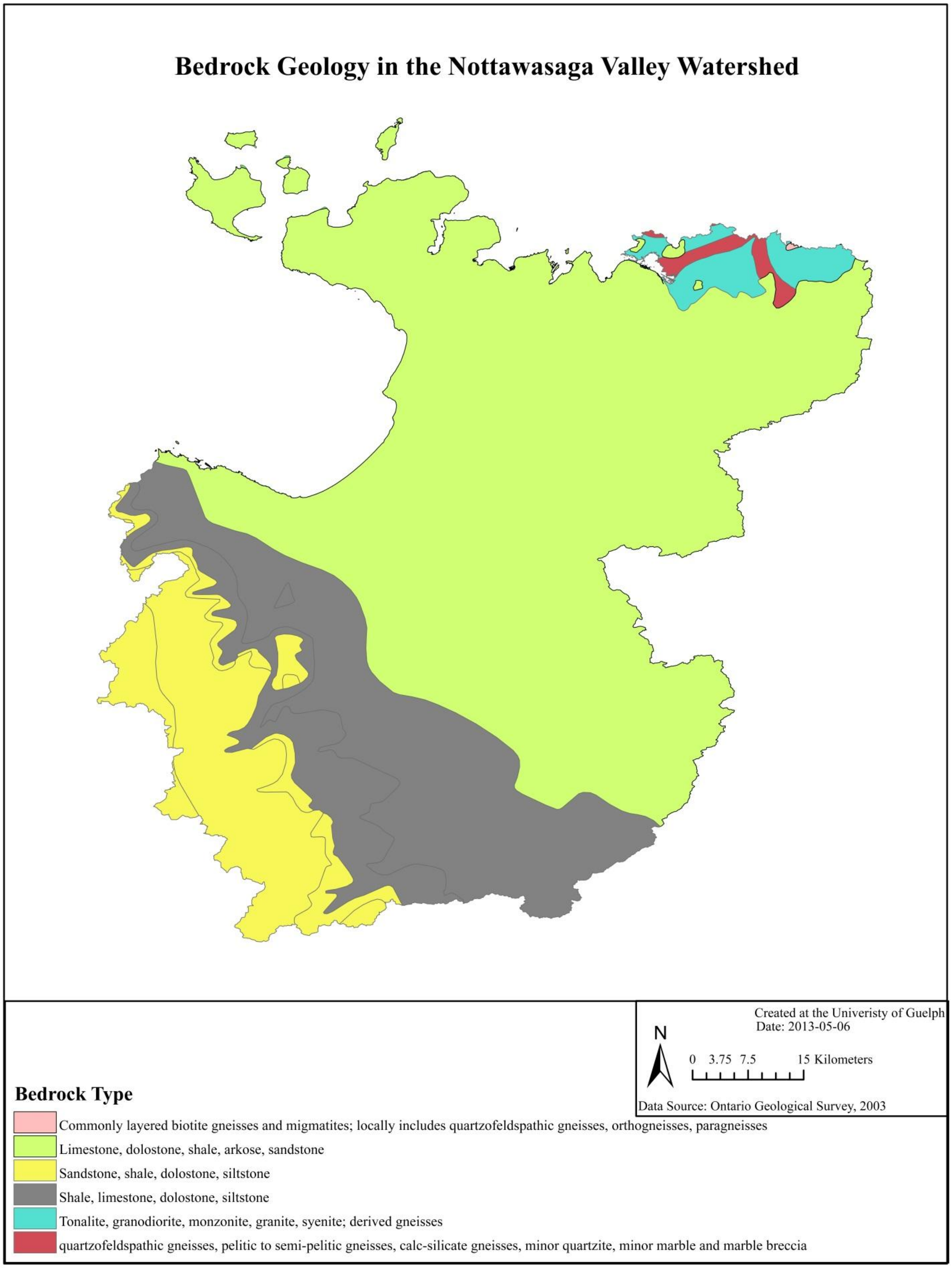

Figure 2.3: Bedrock geology in the Nottawasaga Valley watershed.

2.4.2 Climate

The climate of the area, as with most of Southern Ontario, is a moderate one. The influence of the Great Lakes produces mild summers and winters, and although the lake-effect precipitation can be significant, the overall trend is one of reasonably uniform precipitation throughout the year (Gamble 1997). The lake-effect moderates the hot summer temperatures, while the increased precipitation during the winter produces milder temperatures in the colder months (Gamble 1997). This moderate climate is reflected in data collected from the 1970's through to the early 2000's by an Environment Canada station located in Barrie, Ontario. During that time span the average daily temperatures ranged from -8.1°C to 20.5°C, with the overall yearly average being 6.7°C (Environment Canada 2012). The average yearly rainfall was approximately 700 mm per year, with the summer months experiencing higher rainfall averages (Environment Canada 2012). Snowfall in the winter was averaged at 238 cm per year, with the snow depth at month's end averaging between 2 cm and 16 cm during months with snow cover. December was the month in which the majority of snowfall was recorded (Environment Canada 2012). Total precipitation per year since 1971 has been around the 900 mm mark; however 2012 saw approximately 500 mm of total precipitation, which was much lower than the yearly averages of previous years. An extremely dry summer occurred in 2012 where August received only 8 mm of rain (Environment Canada 2012). While both temperature and precipitation totals fluctuate, the NVCA watershed enjoys a moderate climate with cooler summers and warmer winters, mostly due to the lake-effect.

2.4.3 Land Use

There are many different land uses within the Nottawasaga Valley Watershed. However, agriculture is certainly the most dominant as it encompasses the majority of the areas in each of the subwatersheds (see Figure 2.4). Roughly 150,000 ha of the watershed are used for agricultural practices by nearly 2000 farms (NVCA 2005). Farms are used to raise livestock and grow crops such as corn, alfalfa, barley, as well as potatoes in the regions with sandy soils. The varying topography and soil types within the watershed create a variety of different agriculturally productive sites. The topographically flat areas allow for sod farm operations while Georgian Bay and the Niagara Escarpment create conditions for apple production (NVCA 2005).

Wetlands cover roughly 12% of the Nottawasaga Valley Watershed and can be found on poorly drained lands (SPC 2007). Approximately 34.5% of the total area of the watershed is covered in natural vegetation; the percentage varies across subwatersheds. Much of the land that is not covered in natural vegetation has been converted to agricultural land. Forests in the watershed are considered to be healthy for the most part and occupy roughly 22.5% of the watershed, again this varies across subwatersheds (see Figure 2.4) (SPC 2007).

Table 2.2: Land use in the subwatersheds of the Nottawasaga Valley watershed (LSRCA 2006).

Subwatershed	% Agricultural Land	% Forested Land	% Urban Area
Upper Nottawasaga	64	26	2
Boyne River	72	17	6
Pine River	56	33	5
Mad River	63	20	2
Coates Creek	69	13	2
McIntyre	83	6	4
Marl Creek	60	25	2
Matheson Creek	49	30	5
Black Creek	38	20	2
Bear Creek	50	20	12
Innisfil Creek	78	18	3
Lower Nottawasaga	62	17	6

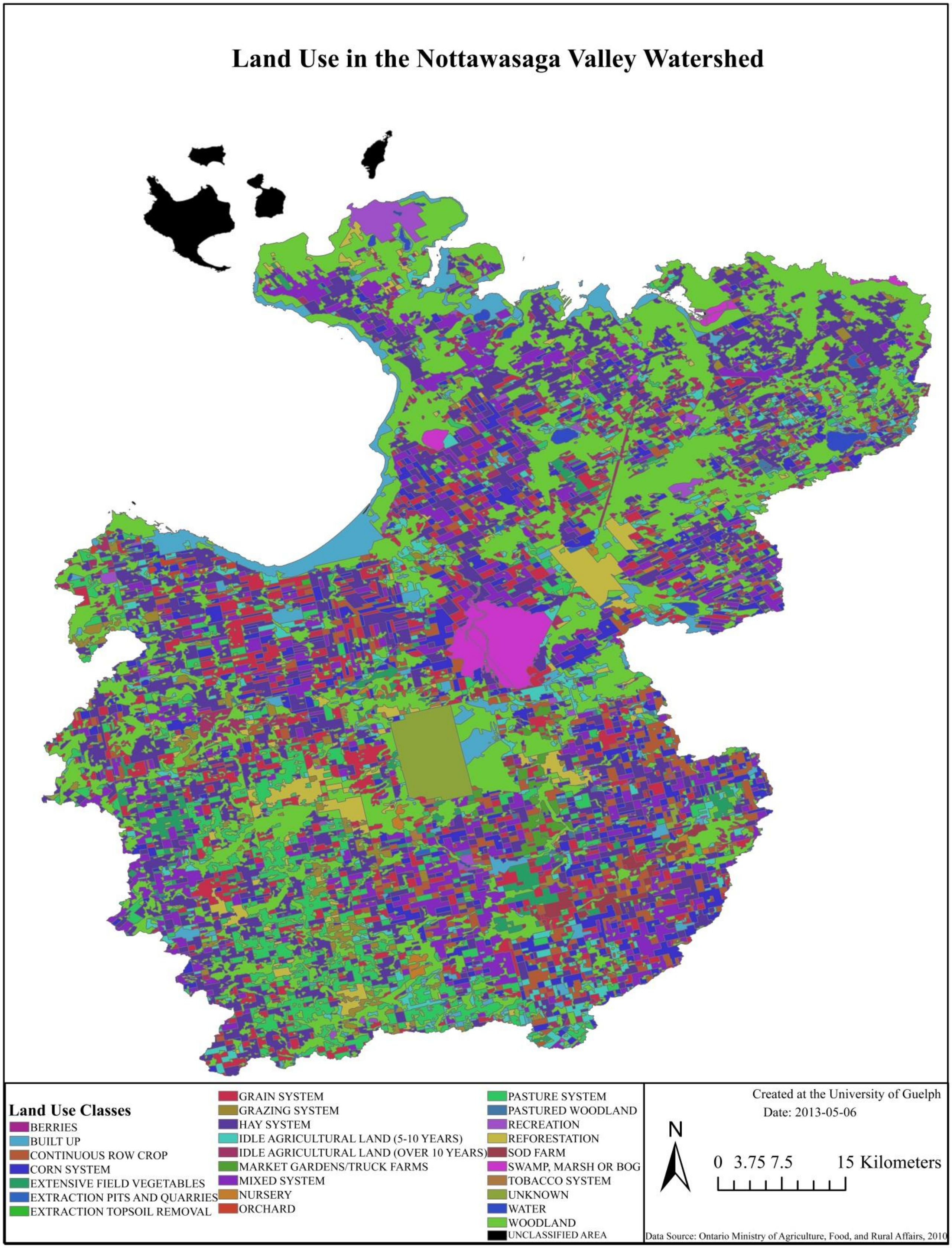

Figure 2.4: Land use in the Nottawasaga Valley watershed.

2.4.4 Soils

2.4.4.1 Soil Types in the Nottawasaga Valley Watershed

There are one hundred and one (101) identified soils in the county with variations in soils more numerous than in other parts of Ontario. Soils tend to develop acidic conditions due to the cool, humid climate in the region (Hoffman et al. 1962).

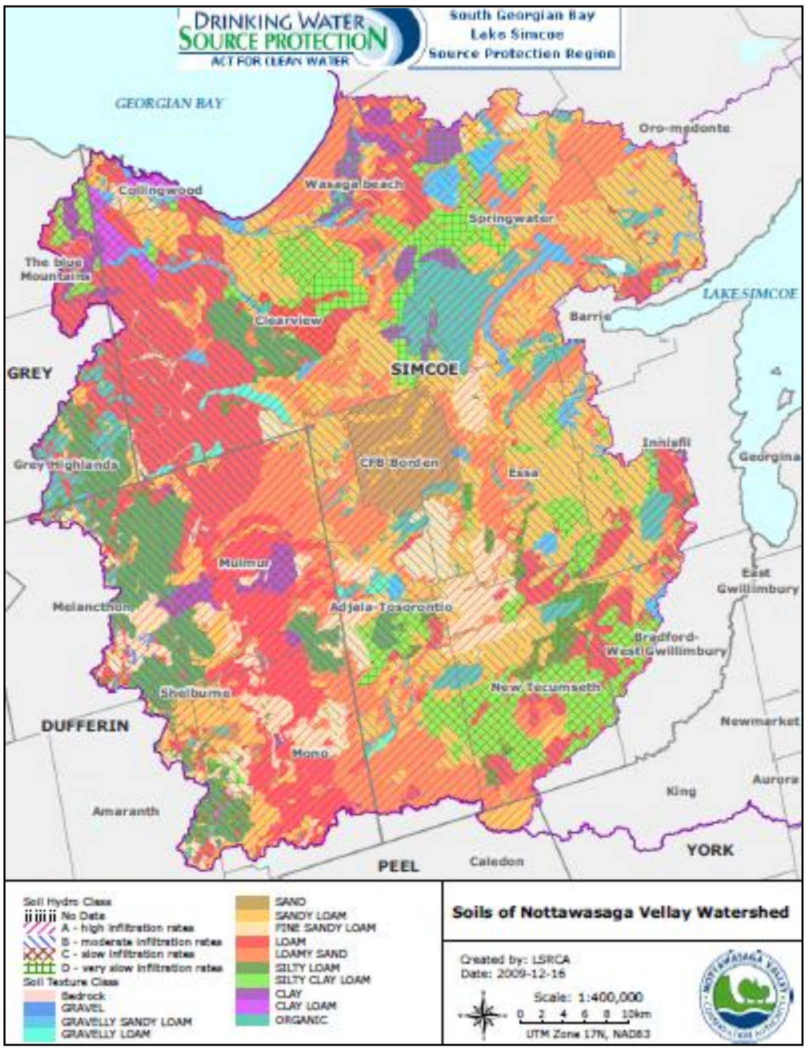

Figure 2.5: Soils of Nottawasaga Valley watershed (SPC 2011).

Table 2.3: Areas of dominant soil types in the Nottawasaga Valley watershed (Adapted from Hoffman et al. 1962).

Soil Type	km^2	Percent of Total Watershed Area
Tioga Soil Series – Loamy sand, Sandy Loam and Fine Sandy Loam	599.7	14.7
Vasey Sandy Loam	415.2	9.9
Bondhead Loam	339.9	8.1
Alliston Sandy Loam and Fine Sandy Loam	266.7	6.3
Tioga loamy sand – Vasey Sandy Loam Complex	266.7	6.3
Muck	245.2	5.8
Schomberg Silty Clay Loam and Silt Loam	205.6	4.9

Table 2.4: Areas of soil drainage classes in Simcoe County (Adapted from Hoffman et al. 1962).

Drainage Class	km^2	Percent of Total Area
Good	2731.6	63.2
Imperfect	686.8	16.2
Poor	630.9	14.6
Very Poor	256.6	6.0

Tioga Soil Series: Loamy sand, Sandy Loam and Fine Sandy Loam (14.7%, 599.7 km^2)

The Tioga series represents a large proportion of soils in Simcoe County and is located in every township within the county. The series includes loamy sand, sandy loam and fine sandy loam soil types (Hoffman et al. 1962). Topography is generally smooth with long slopes for this series. This podzolic soil was developed from outwash materials (Hoffman et al. 1962). Tioga soils are well drained and have a low moisture holding capacity. Nearly all of the Tioga soils have been cleared for agricultural use. Most crops require fertilizers such as phosphorus, potassium and nitrogen as well as irrigation to be suitable for farming. This type of soil is of particular concern for wind driven soil erosion as there are areas where soils have had the surface and a large portion of subsoil eroded (Hoffman et al. 1962). Wind erosion is of particular concern for tobacco crops where soil is not covered year round (Hoffman et al. 1962). It is suggested that windbreaks should be used to reduce erosion and, where soils are not suitable for crop growth, they should be reforested due to erosion concerns (Hoffman et al. 1962).

Vasey Sandy Loam (9.9%, 415.2 km^2)

The topography of the Vasey soils is smooth, moderately to steeply sloping (Hoffman et al. 1962). The rolling topography and nature of the soil means that the soils have good drainage conditions. The Vasey series developed on till and is a Grey-Brown Podzolic soil (Hoffman et al. 1962).The soils are prone to erosion if cover is not provided on the steeper slopes. Vasey soils are used for general farming.

Bondhead Loam (8.1%, 339.9 km^2)

The Bondhead soils occur at the tops of hills and ridges and erosion may be severe on steep, cultivated slopes. This soil type was developed on till. The topography is moderately smooth to steeply sloping and drainage is good (Hoffman et al. 1962).

Alliston Sandy Loam and Fine Sandy Loam (6.3%, 266.7 km^2)

The Alliston series of soils was developed from outwash materials and is a podzolic soil that is imperfectly drained (Hoffman et al. 1962). It is associated with Tioga soils with the main difference being drainage (Hoffman et al. 1962).

Tioga Loamy Sand: Vasey Sandy Loam Complex (6.3%, 266.7 km^2)

The Tioga loamy sand and Vasey sandy loam soil complex is composed of 70 per cent Tioga loamy sand, and 20 per cent Vasey sandy loam. The remaining 10 per cent consists of small areas of other sandy loams, silty clay loam and muck soils (Hoffman et al. 1962).

The topography is rugged and slopes are steep. About one-third of the area is stony on the surface, but stones occur less frequently in the body of the soil (Hoffman et al. 1962). Almost 45 per cent of these soil areas have been reforested on the steeper slopes and where wind erosion has been severe (Hoffman et al. 1962). Mixed farming is carried on over the remainder of the complex. The dominant soils of this complex have a low natural fertility and are very susceptible to erosion (Hoffman et al. 1962).

Muck (5.8%, 245.2 km^2)

Muck is an Organic soil that is very poorly drained. It is commonly found in depressions where water tends to collect, which promotes the accumulation of organic material (Hoffman et al. 1962). For the most part, these areas are covered with forest and are useful as water and wildlife reservoirs.

Schomberg Silty Clay Loam and Silt Loam (4.9%, 205.6 km^2)

Schomberg soils are developed on Lacustrine materials, deep deposits of stratified clay and silt loam (Hoffman et al. 1962). Soil is a Grey-Brown Podzolic and is well drained (Hoffman et al. 1962). Topology ranges from moderately to steeply rolling and slopes are short. Soils range from silt loams to silty clay loam and are among the best fine textured soils in Ontario (Hoffman et al. 1962). Erosion is a concern with these soils as very little forest cover remains, but can be managed with best management practices (Hoffman et al. 1962).

2.4.5 Vegetation

2.4.5.1 Forest Vegetation

According to the NVCA 2007 Watershed Report Card, forest cover within the watershed is generally healthy. Terrestrial and riparian vegetation is important in that water quality is improved through the filtering action that roots have on sediment and stormwater discharge (NVCA 2006b). Although extensive efforts have been made to reforest marginal agricultural land, more needs to be done to further increase or maintain vegetation cover in this highly disturbed area (NVCA 2007a). The looming pressures of urban and agricultural expansion continue to put these ecologically important areas at risk (NVCA 2006a).

The forest cover of the entire watershed is approximately 32.8%, which is just slightly above the 30% minimum that Environment Canada suggests is needed for a healthy and functioning ecosystem of this kind. Forest cover varies between subwatersheds as each may have slightly different topography or weather conditions influencing it. The subwatershed range was 19.1 – 46.3%, and received grades ranging from "D" (lowest) to "A" (highest). This wide range may be due to the fact that some areas will have higher forest cover due to their undesirable agricultural land, while those of high agricultural productivity will have low forest cover. For example, abundant forests of the upland occur along sediment-mantled slopes of the Niagara Escarpment as well as the rolling hills of the Oro and Oak Ridges Moraines, which do not represent highly suitable conditions for agriculture. Similarly, the low-lying areas above the Escarpment and in the Simcoe Lowlands foster extensive forests situated around the characteristic swampy areas. The forest cover in the watershed valley is mainly coniferous and mixed. The forest interior, which lies about 100 m from the forest edge, is especially important for sensitive or endangered animals such as those of several forest bird, mammal, and reptile and amphibian species. The interior forest cover of the entire watershed is approximately 10.8%, which again falls just slightly above the 10% minimum that Environment Canada suggests is needed for healthy function. The subwatershed range for forest interior was between 3.0% - 19.8%, meaning areas received grades of "F" to "A." Lastly, riparian cover (vegetation relating to wetlands or beside rivers and streams) covers 42.6% of the entire watershed and receives a grade of "C." Environment Canada suggests that over 75% of a stream's length should be covered with streamside forest cover, as this sort of vegetation has a critical role in filtering pollutants and supporting fish and other wildlife habitats. The subwatershed range for riparian cover was 28.8 – 56.8%, receiving grades from "B" to "D" from Environment Canada (NVCA 2007a).

2.4.5.2 Aquatic and Wetland Vegetation

Wetlands are areas that consist of marshes or swamps. The aquatic vegetation of these areas serve as biological filters of sediments and other bound contaminants, and also provide food or homes to countless species (NVCA 2006b). Large wetland areas can be found within the NVCA watershed along the Dundalk Plain above the Niagara Escarpment as well around the central Simcoe Lowlands. The Georgian Bay shoreline also fosters conditions for narrow wetlands, which run along the river valley. Unsurprisingly, many wetland areas within the watershed are at risk due to anthropogenic influences. This has prompted mitigation efforts to specifically focus on preventing further development and alteration around these sensitive areas. The NVCA is particularly special as both the Minesing Wetlands (located in the center of the watershed) and the marshes along the Collingwood shoreline are habitats that are considered to be globally significant and rare. This is because they are home to unique flora and fauna species (NVCA 2007a).

According to the NVCA 2007 Watershed Report Card, wetlands within the watershed are generally “good”, but require actions to help improve the current status. Wetland cover of the entire watershed is at 12.0%, giving it a “B” grade. This is just slightly above the 10% minimum suggested by Environment Canada for a healthy and functioning ecosystem of this kind. The subwatershed range of wetland cover is 5.8-20.2%, resulting in a grade from “F” to “A” across the area. Wetland buffers, which are areas of vegetation next to wetlands or other water bodies, cover 37% of the entire watershed. This gives them a “C” grade. The range across other subwatersheds is 24.4 – 50.5%, resulting in a “D” to “B” grade (NVCA 2007a). Studies carried out by the Lake Simcoe Region Conservation Authority in 2008 found about 20 plant species present in Lake Simcoe, three of which were invasive (LSRCA 2012).

2.4.6 Hydrology

According to the watershed hydrology study by MacLaren Plansearch Inc. (1988), the complex network of rivers and streams in the Nottawasaga Valley collect surface runoff and discharge this water into its outlet at Georgian Bay. Along its 122 km main channel length, the Nottawasaga River drops 310 m before reaching its outlet in Georgian Bay. This river has a gradient that varies widely from 0.11 to 19 m/km (LSRCA 2013). This main channel flows in a northeasterly direction for the first 42 km and then turns north (MacLaren Plansearch Inc. 1988). As it enters the Simcoe lowlands south of Minesing Swamp, the Nottawasaga River travels north through the swamp towards Jack's Lake. At this point, the river changes its path to flow west for 6 km and then proceeds to meander towards the Wasaga Beach sand dunes, which it passes through to reach its Georgian Bay outlet (MacLaren Plansearch Inc. 1988).

The Boyne River, Mad River, Pine River, Innisfil Creek and Willow Creek comprise the five main tributaries of the Nottawasaga River (MacLaren Plansearch Inc. 1988). The three rivers are located on the west side of the watershed while the two creeks are found on the east side. Furthermore, Silver Creek, Black Ash Creek, Pretty River and Batteaux River are considered important streams as they discharge directly into the outlet at Georgian Bay. The Niagara Escarpment causes these streams to have steep gradients in their upper reaches, which flatten out as they draw near the outlet. This watershed is also characterized by a number of marsh areas and wetlands, including Minesing Swamp, Osprey Wetlands, the Beeton Flats and the Bailey Bog (MacLaren Plansearch Inc. 1988). According to the Lake Simcoe Region Conservation Authority (2013), the Nottawasaga Valley watershed is considered unusual as it is characterized by an apparent lack of natural lakes. The only notable lakes are Edward Lake, Little Lake and Marl Lake, which have a combined surface area of 3.58 km^2 (MacLaren Plansearch Inc. 1988). The return period flows of the Nottawasaga Valley watershed are characterized by highest peak flows that occur at different times along the streamcourse. Additionally, the regional flood simulation component of this study revealed that the Minesing Swamp caused notable peak flow attenuation.

2.4.7 Topography

Surface topology within the Nottawasaga Valley watershed ranges from 542 m to 160 m above mean sea level with the average altitude of 244 m (Hoffman et al. 1962; SPC 2011). The topography is reflective of the physiographic regions that make up the watershed. These regions have been formed by glacial processes and include areas of drumlins, moraines and a portion of the Niagara Escarpment where the relief is most rugged (Hoffman et al. 1962). Land generally slopes in a northerly direction with a height of 305 m in Adjala Township to 103 m near the shore of Nottawasaga (Hoffman et al. 1962). Relief in the area is mainly gently undulating with hilly areas in the east and southern parts of the county (Hoffman et al. 1962).

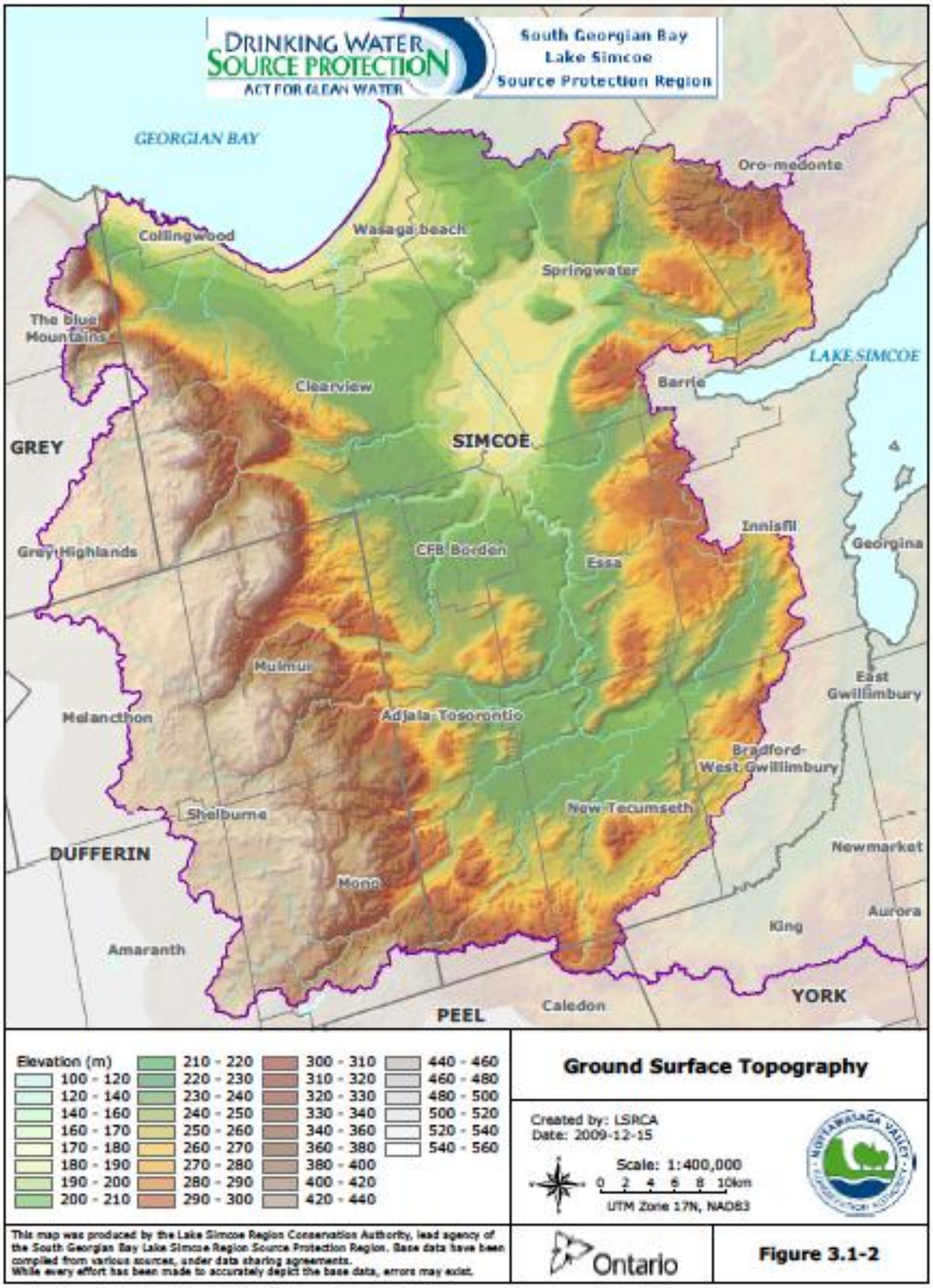

Figure 2.6: Ground surface topography of the Nottawasaga Valley watershed (SPC 2011).

3.0 Literature Review

3.1 Factors Influencing Soil Erosion

Wind erosion is the detachment and relocation of soil particles by wind. The minimum velocity necessary to cause this erosion is known as threshold velocity (Ravi et al. 2006; Blanco and Lal 2008). Soil erosion due to wind can be caused by many factors, including climatic factors, surface properties of the land, soil characteristics and land use and management (Weinan et al. 1996; Ravi et al. 2006; Blanco and Lal 2008). Climatic factors influencing soil erosion include temperature, wind speed and duration, air humidity and precipitation. Surface properties of the landscape, which also influence the level of wind erosion, include slope, surface roughness, slope length and width, and residue cover. Aggregate stability and size, particle size and density, organic matter and water content comprise the soil characteristics that will influence erodibility. Finally, the way land is used and managed can be a major factor in making the soil more or less prone to erosion. For example, tillage, use of cover crops and windbreaks, type of crops grown and amount of residue left on the soil surface. Wind erosion removes the valuable topsoil necessary for successful crop production, which increases the cost of production and causes damage to plants through sandblasting (OMAFRA 1994; Tatarko 2004; Lyon and Smith 2010). Tomato yields can be reduced by 50% from harsh sandblasting. Wind erosion can expose seeds, bury plants and cause uneven growth (OMAFRA 1994). Understanding the factors that influence wind erosion enables the implementation of preventative measures that will effectively reduce P transport by soil particles.

3.1.1 Wind Velocity

The wind speed required to move soil particles depends on vegetation cover as well as soil type and particle size, as stronger winds are necessary to move larger particles. A wind velocity of approximately 8 m/s at 2 m above the soil surface is required to initiate the movement of soil particles (Blanco and Lal 2008). However, soil movement in a highly erodible field can be initiated by a wind speed of less than 3 m/s at 0.5 m above the soil surface. According to Lyon and Smith (2010), a wind speed increase from 9 m/s to 13.5 m/s triples the erosion rate. The drag force between the soil surface and the atmosphere increases as surface roughness increases. Thus, in moving away from the soil surface, the drag force decreases and the wind speed increases. Small, uncovered, loose and dry soil particles are the most susceptible to erosion. Soil erosion increases exponentially with increased wind velocity (McCauley and Jones 2005; Blanco and Lal 2008).

3.1.2 Particle Size

Soil particles are transported by wind via suspension, saltation and surface creep. The method of transportation is dependent on the size of the particle. Suspension is the transport of particles less than 0.1 mm diameter in the air as dust or haze. Though suspension is only responsible for 30-40% of particles transported by wind, most nutrients are transported by these particles through suspension (Troeh et al. 1999). Saltation is the bouncing of particles 0.1-0.5 mm in diameter and accounts for the majority of eroded particles (approximately 50-70%). Surface creep is the erosion of particles 0.5-2 mm in diameter by rolling and transports 5-25% of total wind erosion (White 1997; McCauley and Jones 2005; Lyon and Smith 2010).

3.1.3 Soil Structure

The formation of aggregates is a vital factor in determining the soil's susceptibility to wind erosion. Aggregate formation is important as it helps soil particles stick together and resist erosion. For stable soil aggregates to form a reduction in soil tillage is required (especially during summer fallow) and the soil must have an adequate supply of organic matter. The wind erosion of soil is also influenced by clay content and surface area (Blanco and Lal 2008; Sharratt et al. 2012). The dry aggregate size distribution determines the erodibility of the soil by wind. For example, soil aggregate material with a diameter of less than 0.84 mm is considered to be the most susceptible to wind erosion (Zobeck 1991). When low in organic matter, sandy loam and sandy soils form aggregates with weak bonds and are most at risk for erosion. Soils with a fine texture usually develop strong aggregates that are resistant to wind erosion. Soil that is dry and has been worked or managed (i.e. through tillage) is increasingly prone to soil erosion (Blanco and Lal 2008; Sharratt et al. 2012). A common management strategy is the adoption of minimum tillage, which can produce 50% less soil loss by leaving 15% more residue cover than conventional tillage (Sharratt et al. 2012). In addition, minimal soil crusting (which is usually cited as a soil issue) could potentially slow erosion by 5-5000 times depending on wind speed (Li et al. 2004).

3.1.4 Moisture Content

Moisture content and its influence on a soil's susceptibility to wind erosion is expressed in a simple inverse relationship: as soil moisture content increases, wind erosion decreases. A wet soil is more resistant to wind erosion than a dry soil as a result of the cohesive force of water. However, soil moisture is easily lost in bare sandy soils that are exposed to environmental elements such as wind and sun. Ensuring that the soil is covered with an adequate amount of organic residue will help conserve soil moisture and prevent soil erosion (Tatarko 2004; Ravi et al. 2006; Moreno et al. 2011). Research by Cornelis et al. (2004) shows that a soil surface has to dry to a moisture content of about 75% of the moisture at -1.5 MPa for wind erosion to occur. Once at this moisture level, a remarkable decrease in the threshold shear velocity occurs. However, soils do not dry evenly and patches of drier and wetter soil can exist. This uneven moisture content can impact the amount of sediment transport that is occurring over an existing soil surface.

3.1.5 Surface Roughness

Large fields are prone to soil erosion because these characteristically flat, smooth and bare fields lack surface roughness and thus allow for the wind's energy to build substantially. Surface roughness helps to protect the soil from wind by interfering with wind flow and minimizing the negative effect of wind on soil. Roughness also influences soil temperature, water storage and evaporation rate and plays a role in trapping eroded particles. Aggregates, ridges and clods in the soil surface contribute to surface roughness. Providing surface cover increases surface roughness and is one of the most effective strategies to protect against erosion. This strategy can be implemented using cover crops, standing residues, and flat residues (OMAFRA 1994; Moreno et al. 2011; Sharratt et al. 2012).

3.1.6 Land Use and Land Cover

Land use and land cover have a significant impact on land degradation and soil erosion (Sharma et al. 2011). In considering soil loss, the research by Sharma et al. (2011) found that the conversion of land to cropland use was the most damaging to the watershed whereas conversion to forest was the most effective at controlling soil erosion. Intensive agricultural production in unsuitable conditions can increase a soil's susceptibility to erosion (Cebecauer and Hofierka 2008). Therefore, selections of crop and land cover are important factors in preventing and controlling soil loss.

Human activities change over time, contributing to the continuous alteration of both land use and level of soil erodibility (Egabi et al. 2012). Depending on the land use change, soil erosion processes can either be accelerated or minimized. Sharma et al. (2011) attributed an increase in soil erosion in an agricultural watershed to the reduction of forest and increase in cultivation practices. Cebecauer and Hofierka (2008) found that land cover and crop rotation changes significantly affect soil loss from erosion. It is important to examine and understand the human influence on land use and cover in order to recognize the effects that changing land use and cover can have on soil erosion potential at the watershed level (Egabi et al. 2012).

3.2 The Role of Windbreak Systems in Controlling Wind Erosion and Providing Environmental Benefits

Windbreaks are physical barriers used to control wind speed and reduce wind erosion (Brandle et al. 2004). They are used to protect fields, homes, barns, roads and watercourses from the effects of wind erosion (LRC and UofT 1994; Current et al. 1995; Brandle et al. 2004).These barriers typically consist of linear plantings of rows of trees or shrubs that collectively act to decrease wind speed. Reduced wind speeds leads to decreased soil particle transportation and therefore less deposition in areas protected by the windbreaks (LRC and UofT 1994; Brandle et al. 2004). Windbreak systems can lead to less extreme fluctuations in air temperature, an increase in relative humidity, reduced evaporation, and improved soil moisture. These improvements can help to bind soil particles together making the soil surface resistant to erosion (LRC and UoT Forestry 1994).Trees planted in a windbreak system reduce erosion by controlling wind elements and obstructing wind gusts. Windbreaks increase the surface roughness and create frictional drag, reducing the wind speed which in turn reduces soil erosion (Cleugh 1998). A continuous, flat field with little vegetation is highly susceptible to wind erosion which can be improved with a physical barrier (Brandle et al. 2004). Windbreak systems force the wind over or around the planted trees, driving a change in direction leading to a reduction in wind speed on the protected side of the windbreak (Brandle et al. 2004).

3.2.1 Windbreak Design and Orientation

Trees can be planted and oriented using a variety of different designs in order to control wind erosion for agricultural systems. Windbreak height is the most important factor for wind speed reduction. A windbreak will decrease wind speed for a length of 30-35 times its height in the leeward direction and 5 times its height in the windward direction (Nordstrom and Hotta 2004). The windbreak height and width delineate the size of the protected area (Blanco and Lal 2008). Wind speed is reduced by 70% at a horizontal distance of 10 times the height of the windbreak and by 20% at 20 times its height. Wind speed reduction is largest at a horizontal distance of 4-6 times the windbreak height (Vigiak et al. 2003). Windbreak porosity is optimal between 40-60%, and density should ideally be around 50% in order to effectively decrease wind speeds enough to reduce soil particle transportation (Blanco and Lal 2008).

3.2.2 Ancillary Benefits

The ability for trees to reduce wind erosion contributes to multiple other advantages that can increase the overall productivity of the land and assist farmers and their families. By creating a physical barrier that obstructs travelling wind, influences on the surrounding environment can be significantly reduced (Vigiak et al. 2003). A microclimate is created with a lower mean wind speed, altered wind direction, decreased turbulence and regulated temperature compared to outside of the windbreak barrier. The sheltered area may experience less extreme fluctuations in temperature, with lower temperatures during the day and warmer temperatures at night compared to unprotected areas (LRC and UofT 1994). Though a 2-3˚C temperature change in protected areas might not seem substantial, it can be of great benefit to crops. These factors contribute to improved crop quality and can lead to an average crop yield increase of 6-44%.

While the degree of benefit to crops varies between crop sites and windbreak design, field crops in Ontario can show yields up to 25% higher with the use of windbreaks (LRC and UofT 1994). The topsoil contains essential nutrients necessary for plant growth. When soil is moved by wind erosion it can become nutrient poor and limit plant growth (Brandle et al. 2004). The topsoil, which is fertile due to a high proportion of nutrients and organic matter, can take many years to build back up if lost (OMAFRA 1994). A reduction in wind erosion helps to moderate how much soil, and therefore nutrients (including P), are moved. The decrease in soil wind erosion can not only minimize P loading into water bodies, but enhance crop yield in surrounding areas by protecting valuable topsoil (Cleugh 1998).

3.3 Knowledge Gaps

There are definitive gaps in the knowledge and research when reviewing the literature pertaining to phosphorus deposition in agricultural watersheds, soil physical properties that influence erosion and the effectiveness of land cover and windbreaks in controlling erosion. The tools currently used to measure atmospheric nutrient deposition are inadequate for many reasons. Wet deposition is calculated more often than dry deposition, which results in misleading results for total nutrient deposition (Anderson and Downing 2006). Dry deposition to wet surfaces, which can significantly contribute to nutrient capture on wet surfaces and impact aquatic systems, is difficult to measure and make distinct from wet deposition (Anderson and Downing 2006). There is little available information on the classification of atmospheric phosphorus deposition in agricultural regions in Ontario.

While there is sufficient information regarding the influence of soil physical properties on wind erosion, information concerning soil moisture content is scarce. A specific recommendation for the soil moisture content level required to reduce soil erosion is missing from the literature. The soil moisture content would vary throughout the changing seasons and depend on climate and location, but a broad guideline would be helpful to indicate the effects different moisture levels would have on soil erosion. There are a limited number of research studies done on agricultural land, or watersheds surrounded by agricultural land, especially in Ontario. While there are many studies done on soil physical properties affecting soil erosion in various countries around the world, these areas do not always have the same physical conditions as Ontario, and therefore are not applicable to the current study area. It was found in many studies that the conversion of land to cropland is the most damaging to a watershed and can potentially increase soil erosion, while the conversion to forest was found to be the most effective at controlling soil erosion in a watershed (Sharma et al. 2011). The effect of specific crop types on soil erosion is lacking in the literature, as the majority of the studies refer to 'cropland' but do not say specifically which crop types were investigated. Crop rotations and crop management practices also have a great influence on soil erosion but different types were not mentioned in the literature.

3.4 The Purpose of this Study

This study will aim to analyse knowledge of atmospheric P transport occurring around farmland and most importantly determine where a windbreak system can be placed to reduce the impacts of this process. The exploration of both temporal variability and spatial distribution of atmospheric deposition in this study will represent important information that can be used to improve the health of the Lake Simcoe watershed. This study will provide research at a site specific level for an agricultural watershed in Ontario. Results from this study can then be applied to locations with similar physical characteristics. Specific land use types, especially cropland, will be examined in the NVCA watershed area. Soil erodibility under various land uses and crop cover, coupled with precipitation data, wind data and soil physical properties, will be used to determine areas of potentially high soil erodibility. Recommendations for the location and orientation of windbreak systems will be made by incorporating collected and analyzed information.

4.0 Goals and Objectives

4.1 Goal

The main focus of this study is to suggest windbreak placement based on analysis of seasonal soil erosion data in the NVCA watershed, including an analysis of factors that influence the erodibility of soils in the area.

4.2 Objectives

1. To research and determine, at the local level, which physical conditions influence wind erosion (wind speed, wind direction, soil dryness, soil particle size, soil texture, soil structure), how these factors influence wind erosion, how windbreaks can reduce wind erosion, and how phosphorus is transported through wind erosion.

2. To determine the distribution of directional wind patterns and associated wind speeds during periods of potential high soil erosion in the NVCA watershed.

3. To evaluate the inputs of the Revised Wind Erosion Equation (RWEQ) by conducting a literature review and determining which field factors (field length, weather factors, soil roughness, etc.) would contribute to different levels of soil erosion.

4. To identify areas of high, medium and low erodibility based on soil and land use information, using GIS analysis.

5. To develop recommendations based on the literature review and analysis of GIS maps, wind rose diagrams and precipitation data. Recommendations will include the preferred orientation of windbreaks based on soil grain size classifications within the area. Wind and precipitation data will also be used to specify which areas are the most susceptible to erosion and where windbreaks should be placed in order to minimize the erosion.

5.0 Methodology

5.1 Literature Review

Research was conducted regarding the conditions that influence wind-based soil erosion. Conditions research included, but was not limited to: wind speed, wind direction, soil moisture, soil particle size, soil texture, soil structure, along with how windbreaks effectively reduce wind erosion and how phosphorus is transported through wind erosion. The four main components addressed in the literature review were as follows:

- Description of the problem, or research question, that this literature review will help to define
- Synthesis/summary of the information that is known followed by a summary of what is unknown and needs to be researched further
- Identification of inconsistencies within the literature
- Formulation of questions or areas of research that need to be researched further in order for there to be a consensus and understanding of the topic

5.2 Wind and Precipitation

Wind speed, wind direction, and precipitation data from 2008-2011 was obtained from Environment Canada for weather stations in the NVCA watershed. Monthly averages of the datasets were calculated and analyzed for the area. Precipitation data was analyzed for five weather stations, including the Egbert, Innisfil Golf Club, Mono, Oro-Medonte and Petun weather stations. Monthly averages were plotted in line graphs for each weather station using Excel. The total monthly sum of precipitation (mm) for the Egbert weather station was analyzed from 2008-2012. For the four other weather stations, total monthly sum of precipitation (mm) was analyzed from 2010-2011. A wind rose diagram was created using wind data for the NVCA watershed. Research and data was analyzed together to determine which time periods and conditions lead to high potential wind erosion. Areas that match these conditions and have a high sensitivity to erosion were mapped for the NVCA watershed.

5.3 Wind Erosion Model

A literature review on the components of the Revised Wind Erosion Equation (RWEQ) was completed to determine which field conditions impacted soil wind erosion. This was then related to actions that landowners can take to reduce the erodibility of their soil. Twelve sources were used for the literature review.

5.4 GIS Analysis

Soil and land cover information was manipulated in GIS to show areas of high, medium and low erodibility in the NVCA watershed. Soil class data was downloaded from Agriculture and Agri-Food Canada to distinguish areas of different soil types in the watershed. Soil erodibility values (K factors) were obtained from the RUSLEFAC handbook published by Agriculture and Agri-Food Canada. Soil erodibility values were assigned to each of the soil types in the watershed from values listed in the RUSLEFAC handbook assuming an average amount of organic matter for all areas in the watershed. Once each soil type was assigned an erodibility value, soil types were classified as having either high, medium, or low erodibility.

Land use information was manipulated in GIS to show areas of high, medium and low erodibility in the NVCA watershed based on various land cover types. Land use data was downloaded from the Ontario Ministry of Agriculture, Food, and Rural Affairs. The RUSLEFAC handbook was used to create a ranking of the erodibility of the soil under various land covers. Land covers were then ranked based on their susceptibility to erosion (i.e. areas of high, medium and low erodibility based on the protection of the surface from different land cover types).

Both the soil and land cover data layers were given the same ranking and colour scheme. Areas of high erodibility were given a red colour, areas of medium erodibility were given a yellow colour, and areas of low erodibility were given a green colour. The soil and land cover layers were then overlaid to produce a final map showing the vulnerability to erosion of various areas in the watershed.

5.5 Windbreak Design

Using information gathered in the literature review and data collected and analyzed (wind, soil, and precipitation data in the NVCA watershed) recommendations were developed for the preferred orientation of windbreaks in the NVCA watershed. By assessing wind direction, wind speed, precipitation and soil type, the prime orientation of windbreaks in the NVCA watershed was determined. Windbreak orientation and location were recommended with the main goal of attaining reduced wind erosion of soil in the NVCA watershed and reduced phosphorus transport into Lake Simcoe.

6.0 Results

6.1 Wind Rose Diagrams

Wind analysis of data from the Egbert (ON) weather station (latitude 44-14 N and longitude 079- 47 W) shows that there is a predominant wind from between 330° and 340° or from a NNW direction. There is also a prominent wind from between 180° and 190° or from a SSW direction. It may appear that wind directions vary significantly month to month, but this is only for very low-level winds of between 1-5 km/hr. The most frequently occurring wind speeds are between 6-20 km/hr, but wind gusts can reach up to 50 km/hr. When examining wind speeds of 30 km/hr or greater (Figure 6.6), which would be needed to move the soil particles, it was found that there were predominant winds coming from the NNW and the SE.

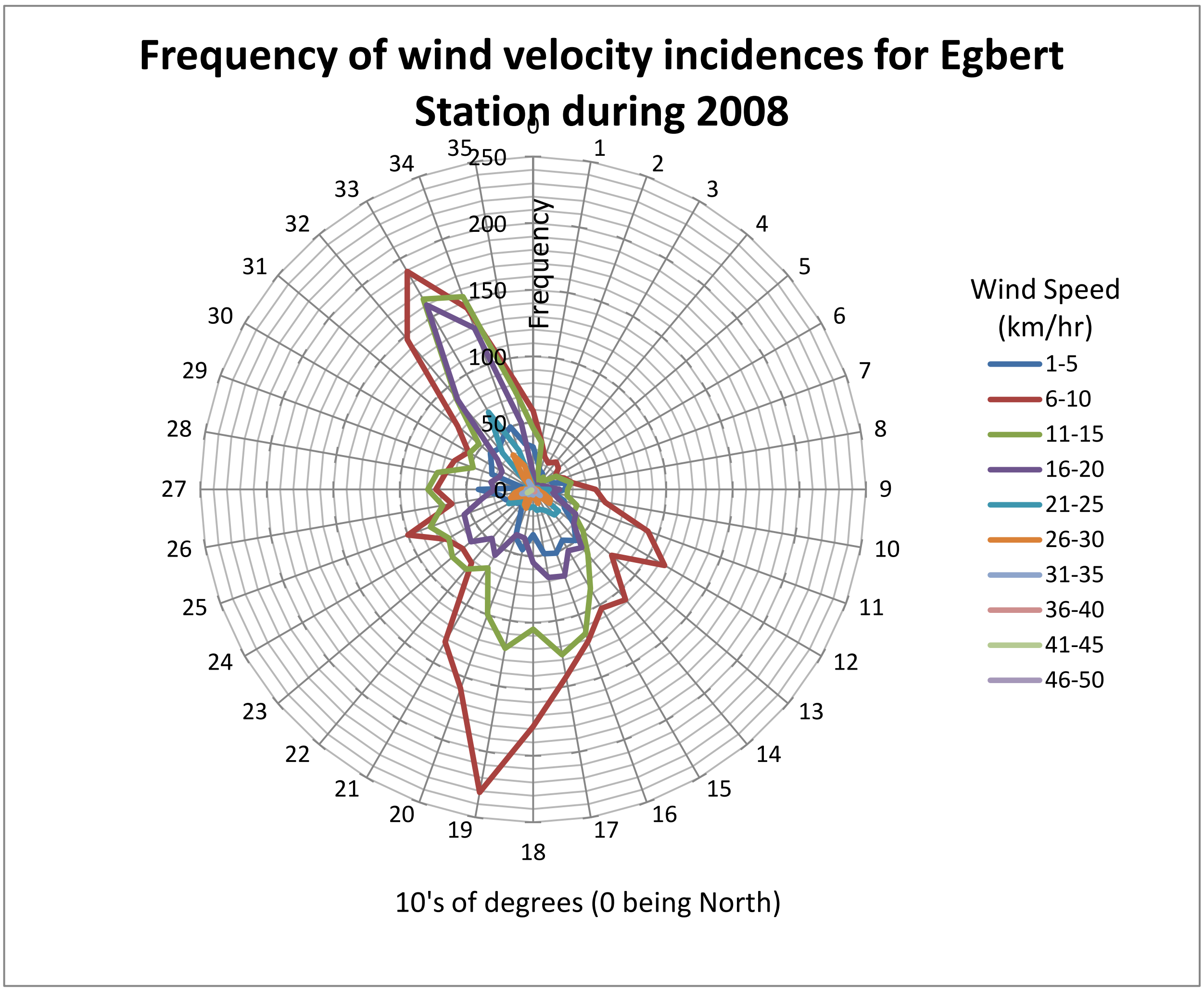

Figure 6.1: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station from January 1st to December 31st 2008.

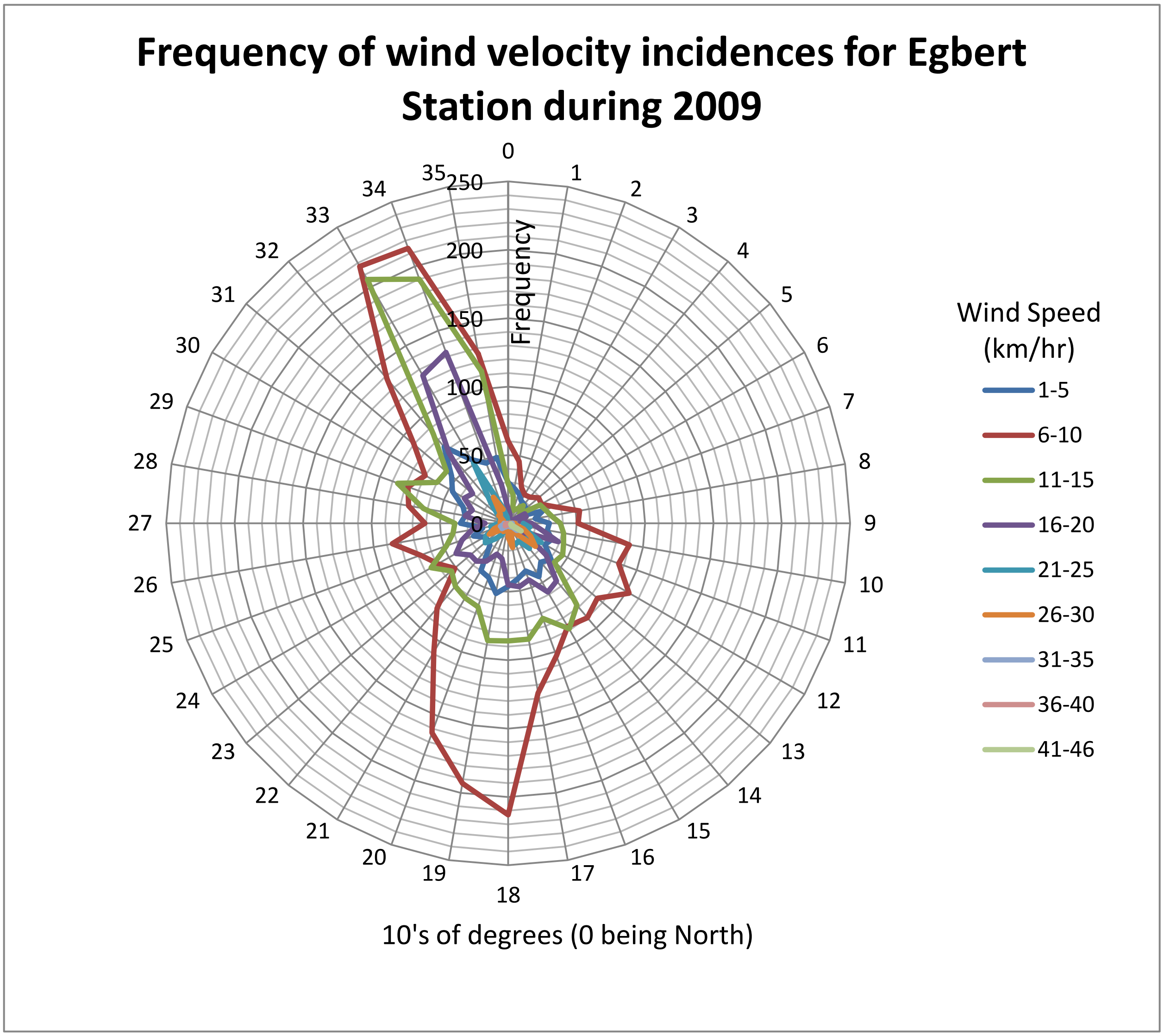

Figure 6.2: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station from January 1st to December 31st 2009.

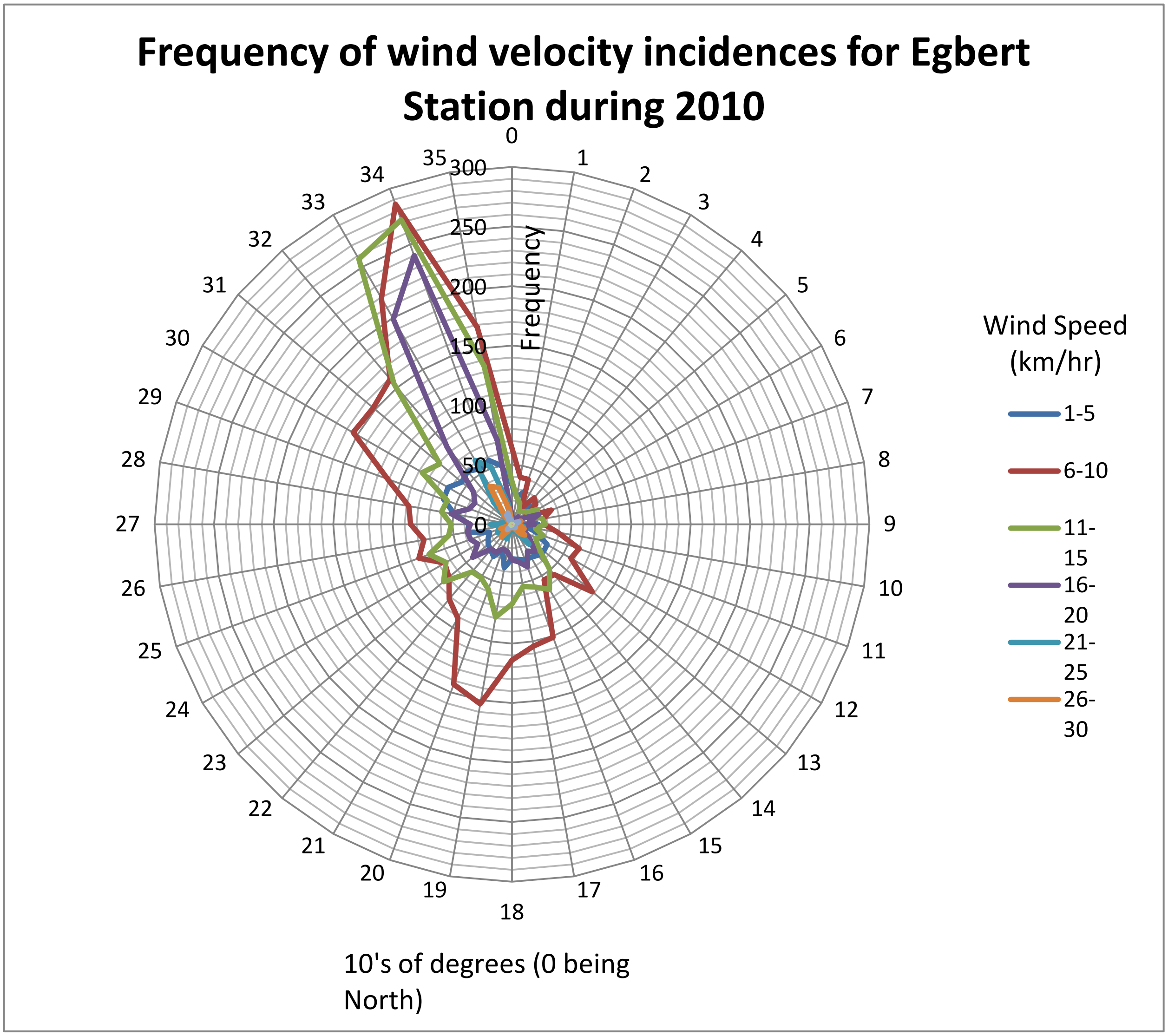

Figure 6.3: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station from January 1st to December 31st 2010.

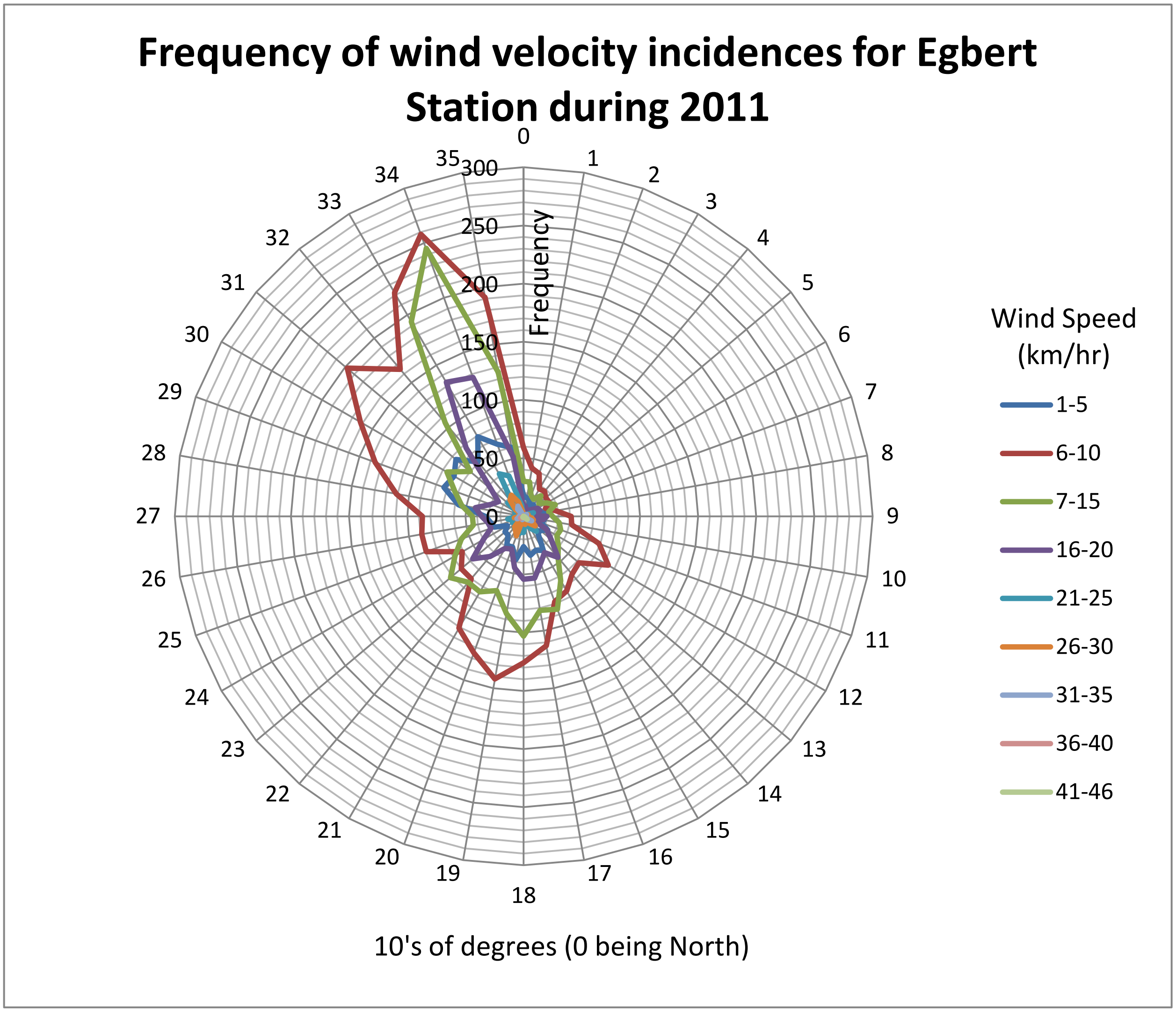

Figure 6.4: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station from January 1st to December 31st 2011.

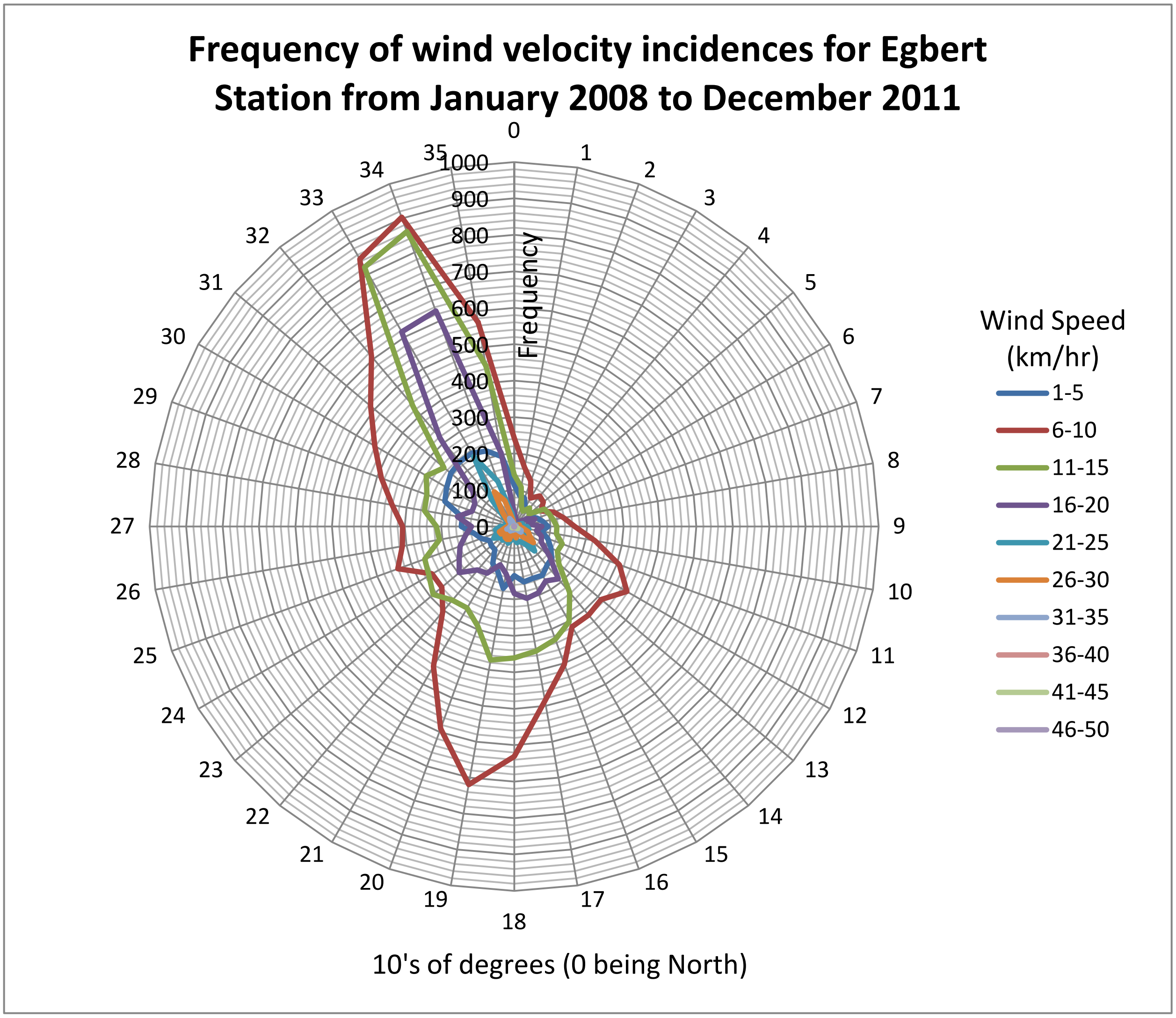

Figure 6.5: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station from January 1st 2008 to December 31st 2011.

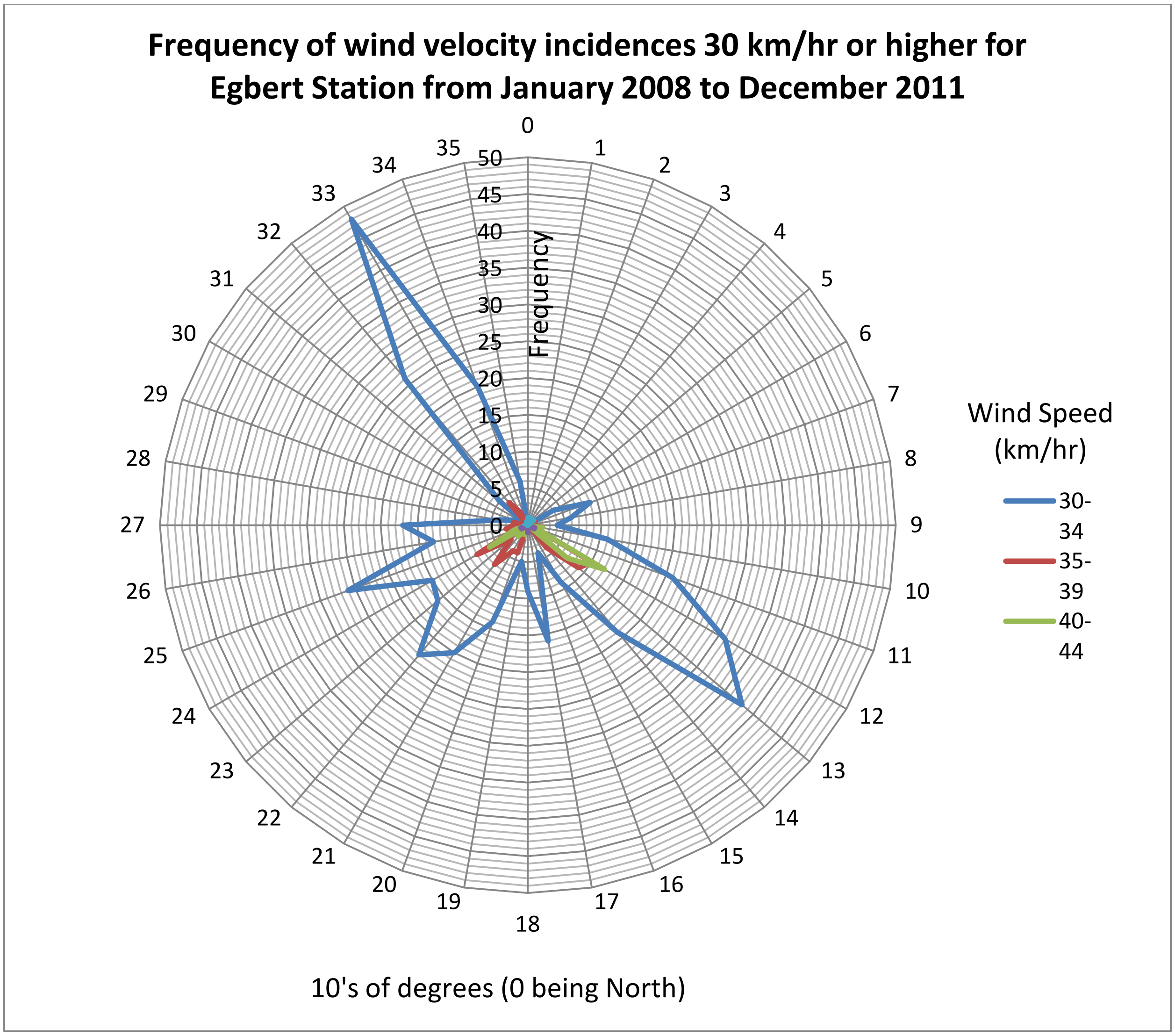

Figure 6.6: Wind rose graph of the frequency of wind speeds above 30 km/hr and directions collected at Environment Canada's Egbert Station from January 2008 to December 2011.

6.2 Precipitation Data Analysis

From data collected at the Egbert weather station, the total annual sum of precipitation was calculated to be 992.5 mm, 951.5 mm, 743.5 mm, 738.5 mm and 556.3 mm for each year from 2008 to 2012. The average sum of annual precipitation at the Egbert weather station was determined to be 796.5 mm between 2008 and 2012.

Table 6.1: Precipitation data collected at the Egbert weather station from January 2008 to December 2012.

Month	2008 (mm)	2009 (mm)	2010 (mm)	2011 (mm)	2012 (mm)	Monthly Average 2008-2012 (mm)
January	69.5	45.8	15.7	22.6	38.9	**38.5**
February	79	65.4	18.5	30.2	30.4	**44.7**
March	70.1	61.4	36	65.3	38.3	**54.2**
April	44.6	96.2	19	74.6	36.8	**54.2**
May	59.2	89.2	89.6	83.1	42.3	**72.7**
June	76	52.3	134.5	39.4	51.6	**70.8**
July	124	117.2	121.9	55.3	92.5	**102.2**
August	118.1	246	39.8	77.9	8	**98.0**
September	133.1	49.3	102.2	71.1	75	**86.1**
October	44.4	66.4	56.5	79.2	83.6	**66.0**
November	95.4	27.8	37.6	87.3	16.4	**52.9**
December	79.1	34.5	72.2	52.5	42.5	**56.2**
Grand Total	992.5	951.5	743.5	738.5	556.3	**796.5**

In 2008, September (133.1 mm) was the wettest month while October (44.4 mm) was the driest month. In 2009, August (246 mm) was the wettest month with an abnormally large amount of rainfall. November (27.8 mm) was the driest month in 2009. For 2010, August (39.8 mm) was unusually dry and June (134.5 mm) was the wettest month. The driest month was April (19 mm). Monthly rainfall sums in 2011 were more consistent, with November (87.3 mm) bringing the most rain and January 22.6 mm) bringing the least. In 2012, July (92.5 mm) was the wettest month while August (8 mm) was the driest with almost no rainfall. On average over the five-year span, July (102.2 mm) was the wettest month and January (38.5 mm) was the driest month.

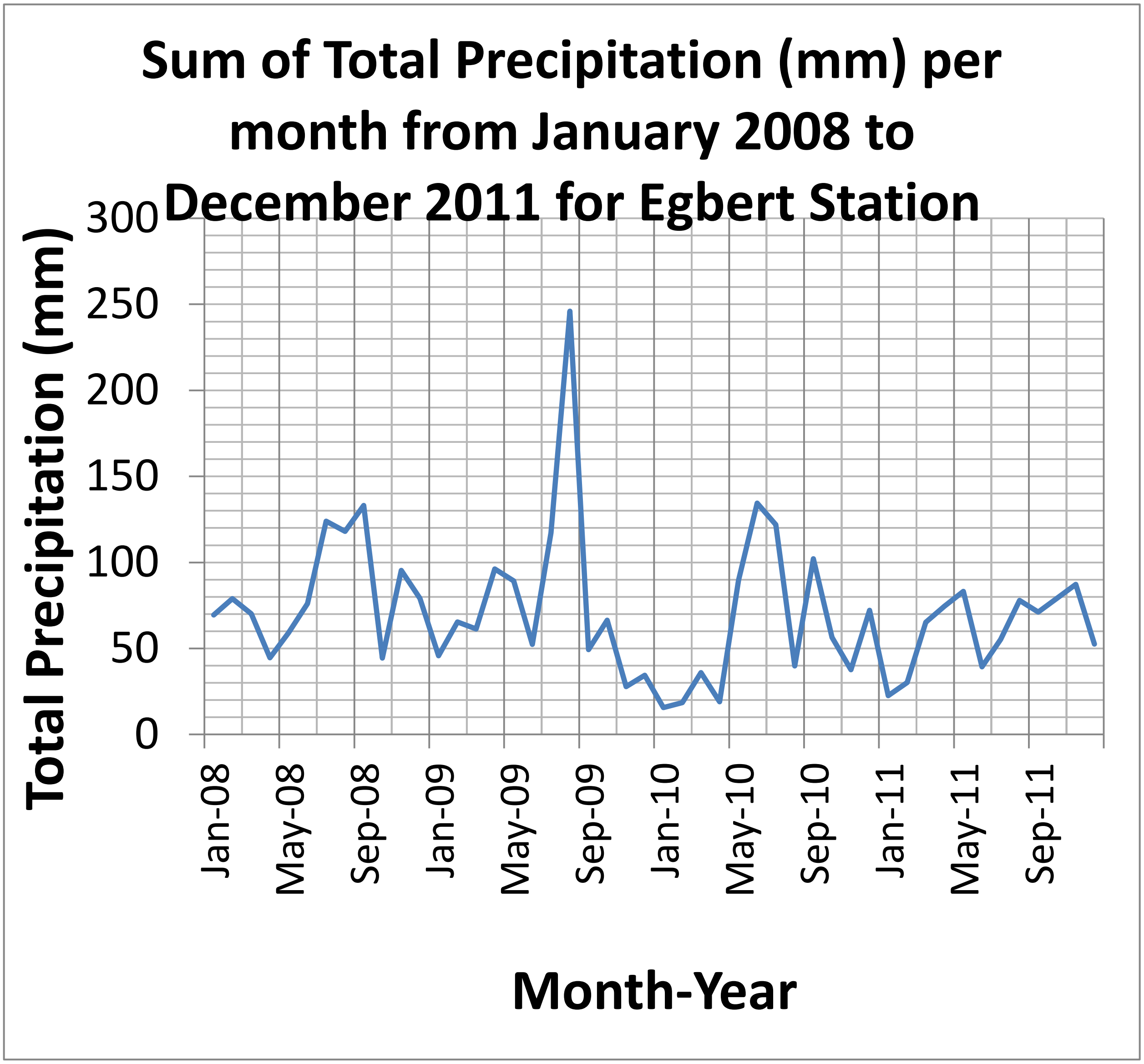

Figure 6.7: A graph of the sum of total precipitation received per month at Environment Canada's Egbert Station from January 2008 to December 2011.

Data were also collected from the Innisfil Golf Club, Mono, Oro-Medonte and Petun weather stations between 2010 and 2011. The general pattern of precipitation at these stations followed the trend from the Egbert weather station, with summer months June and July being characterized by greater rainfall and winter months December and January typically being drier.

6.3 Wind Erosion Model

Since we do not have the information required to carry out a software analysis and model the amount of soil wind erosion occurring in the Nottawasaga watershed, we have decided to evaluate the wind erosion factors instead. The following is an analysis of the various components of the Revised Wind Erosion Equation (RWEQ). Each of the parameters taken into account by the model are identified and explained in terms of their influence on soil wind erosion.

The damaging effects from wind erosion have long been documented. From the historic Dust Bowl in the 1930s, to the sandblasting in a farmer’s field today- it is a problem on both small and large scales. Many factors have been identified as contributors to soil wind erosion and their interactions determine the total amount of soil eroded. The RWEQ is the current model available for prediction of soil loss from a field due to wind. Understanding the different parts of this model and how they influence erosion is key to figuring out how to protect fields and minimize soil loss.

6.3.1 Soil Crust Factor

The soil crust factor (SCF) measures how prone a soil is to forming a crust. The measure of the factor depends largely on precipitation and the clay and organic matter content of the soil (Buschiazzo and Zobeck 2008). According to calculations done by Fryrear et al. (2001), a default value for the SCF in the RWEQ would be around 0.72. Understanding how likely a soil is to form a crust is important in controlling erosion. The RWEQ is one of the few models that even consider crusting as an erosion estimate variable. Using this model beyond single events and linking the SCF to climatic conditions can provide estimates of crust formation and degradation in time. However, the RWEQ would still be viable for use in single event calculations, as it would provide a measure of the degree of soil crusting and subsequent erosion from this soil characteristic (Buschiazzo and Zobeck 2008). Though crusting is usually cited as a soil issue, it can actually reduce erosion by 5-5000 times, based on wind speed (Li et al. 2004).

6.3.2 Soil Roughness Factor

The soil roughness factor (K) takes into account roughness measures other than erodibility (I), such as ridge roughness, for windward slopes. A high soil roughness coupled with large canopy cover (high plant coverage) can result in low or even negligible values of erosion predicted by the RWEQ. This is an important factor in minimizing erosion as understanding how to interpret and manage (increase or decrease) soil roughness can result in effective erosion control (Fryrear et al. 2001).

6.3.3 Weather Factor

The weather factor (WF) is a function of wind, snow and soil wetness and describes (but is not limited to) parameters such as wind speed direction and distribution, air temperature, soil radiation, snow cover and rainfall. Wind values can be adjusted depending on the amount of soil wetness and snow cover. It is necessary to adjust the weather factor wind component based on the number and amount of rainfall and snow events as a soil with increased moisture is less likely to be eroded by wind (Blanco and Lal 2010). The cohesive force of water accounts for this exponential decrease of wind erosion rates with increasing soil water content (Blanco and Lal 2010). Rainfall tends to create a crust or compact consolidated zone in the soil surface, which is more resistant to wind erosion due to increased mechanical stability (Zobeck 1991). According to Environment Canada (2012), the Nottawasaga Valley area receives an average annual rainfall of 700 mm with above average rainfall amounts occurring in the summer months. This is supported by the precipitation data analysis completed for the Egbert weather station (2008-2012) in the NVCA watershed, which revealed an average annual precipitation amount of 796 mm with precipitation peaks concentrated in the summer months of July, August and September. The need for accurate weather data is of paramount importance in erosion estimates as the RWEQ outputs are dependent on the quality of input data. The close relationship between weather conditions and the amount of erosion makes the WF an important parameter in erosion estimates (USDA [date unknown]).

6.3.4 Erodible Fraction

The erodible fraction (EF) is determined from soil properties or from dry sieving procedures (the assessment of particle size distribution i.e. gradation). This measure shows the proportion of soil aggregates most susceptible to erosion. However, the EF only provides static (stationary) representations of the erodible fraction at any given time. This means it does not take into account changes in response to climate or land management occurring over time (Webb and McGowan 2009). Despite this limitation, the EF in conjunction with the wind factor (part of the WF), K (including crop cover) and SCF can be used to effectively determine the maximum transport capacity and transport mass for any field, which is extremely important in soil erosion estimates (Fryrear et al. 2001).

6.3.5 Field Portion

The field portion of the RWEQ takes into account the field size and orientation. Barriers affect wind and depend on the barrier height and density (Fryrear et al. 2001). As wind blows over a soil, the amount of soil transported increases until the soil particles saturate the wind. This is referred to as the saturation point, the maximum amount of soil particles the wind can transport (Bagnold 1941; Chepil 1957). When this saturation point is reached depends on the wind velocity and the characteristics of the soil surface (Chepil 1945, 1957). The wind's ability to carry added soil particles decreases until the wind stream reaches its maximum transport capacity. Therefore, as field length increases and maximum transport capacity is approached, the increase in mass transported decreases until it becomes zero. More abrasion of the soil surface will occur as more soil is carried by the wind, which will dislodge even more soil particles until the maximum capacity is reached (Fryrear and Saleh 1996). Decreasing field length will break up the wind path and help reduce erosion. Windbreaks can reduce field size and break wind flow (OMAFRA 1994).

6.3.6 Hill Height and Slope

Hills are also included as part of the RWEQ. Hills can change wind speed. Based on the height and slope of the hill, erosion could be greater because of greater velocity. Taking hills into account as a separate field lets users adjust for its different characteristics (Fryrear et al. 2001). Hill slope is usually regarded as a concern for water and tillage erosion (OMAFRA 1994). However, it plays a role in wind erosion as well. Erosion occurs first at over-tilled field locations, places where wind is funneled, or the tops of ridges or knolls (AAFC 2012). Wind can deviate around a hill and speed up over crests. Wind speed increases as wind travels up the windward slope of a hill or ridge. The maximum wind speed increase occurs at or close to the crest (Maharani et al. 2009).

6.3.7 Crops on Ground

The crops on ground (COG) factor encompasses standing stalks, flat residue and growing crops. These can all help keep wind away from the soil surface and aid in preventing erosion. OMAFRA's Best Management Practices (1994) recommend keeping at least a 30% residue cover over a field at all times and adequate organic matter levels using manure or crop residues. According to Lyon and Smith (2010), a 30% residue cover will reduce soil loss by 70%, compared to a bare field. Planting cover crops (oats, clover etc.) as soon as possible is suggested as well. Crop rations are also beneficial, as well as alternating row crops with solid-seeded crops. Incorporating cereals and forages in crop rotations will help build soil organic matter levels, which is important to prevent soil erosion (OMAFRA 1994; Lyon and Smith 2010). Transport capacity of the wind can be significantly reduced with a little amount of residue (Bilbro and Fryrear 1994). Standing residue keeps the wind from reaching the soil surface and is four times better at preventing soil erosion than flat residue. Growing crops serve the same purpose once they have grown enough to be able to prevent wind (AAFC 2012).

The RWEQ is a useful tool that farmers and landowners could apply to their individual fields to see where soil management could be improved. Different factors in the equation can be manipulated to see how erosion would be impacted if practices were altered. For wind erosion to be mitigated, action must be taken to control the components that are influenced by human activities. Simple practices such as increased crop residue cover and reduced tillage provide tremendous protection against wind erosion. By making an effort to protect soils from wind erosion, negative environmental consequences such as P loading into water bodies could be avoided or reduced in the future.

6.4 GIS Analysis

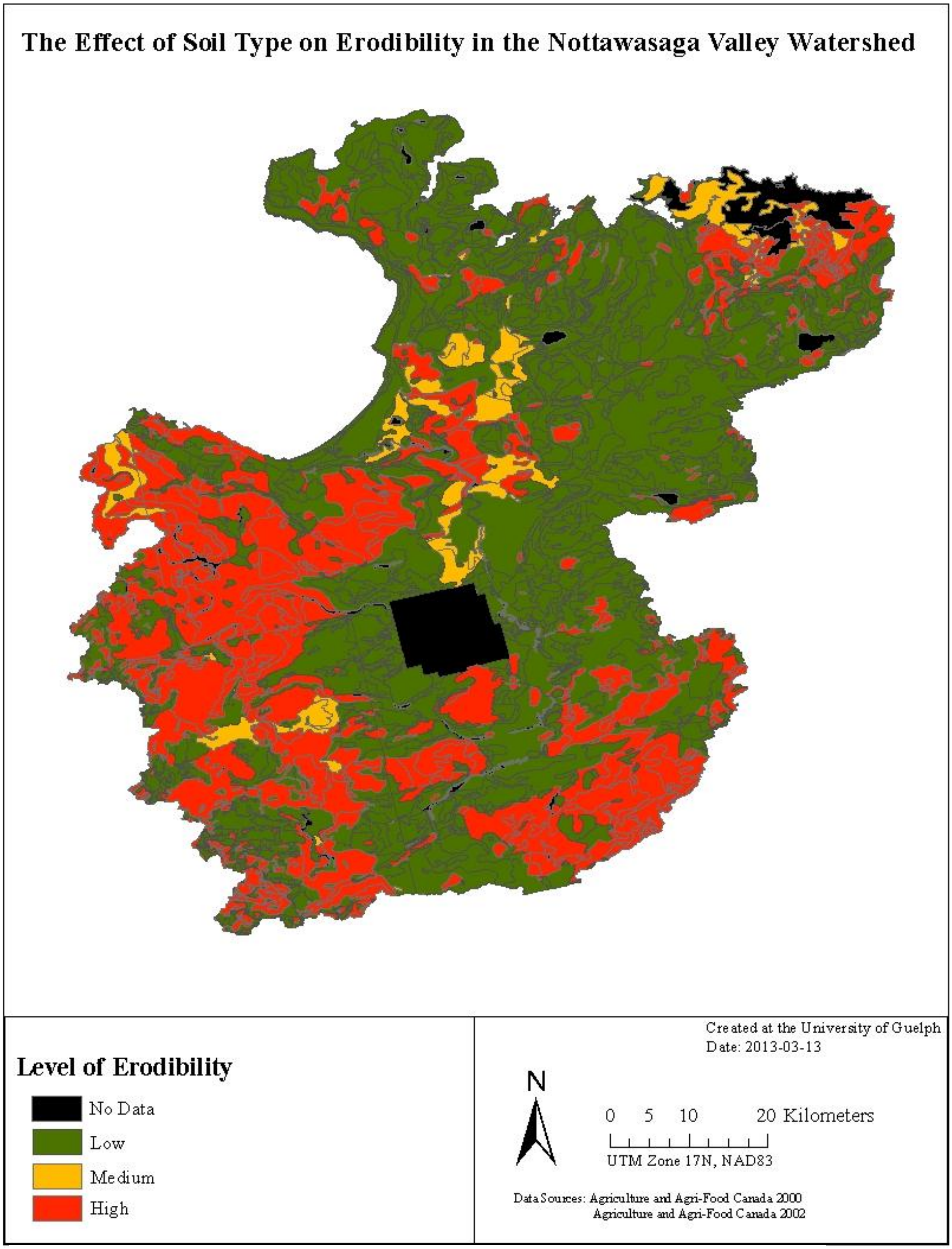

Figure 6.8: A GIS analysis of the effect of soil type on erodibility in the Nottawasaga Valley watershed.

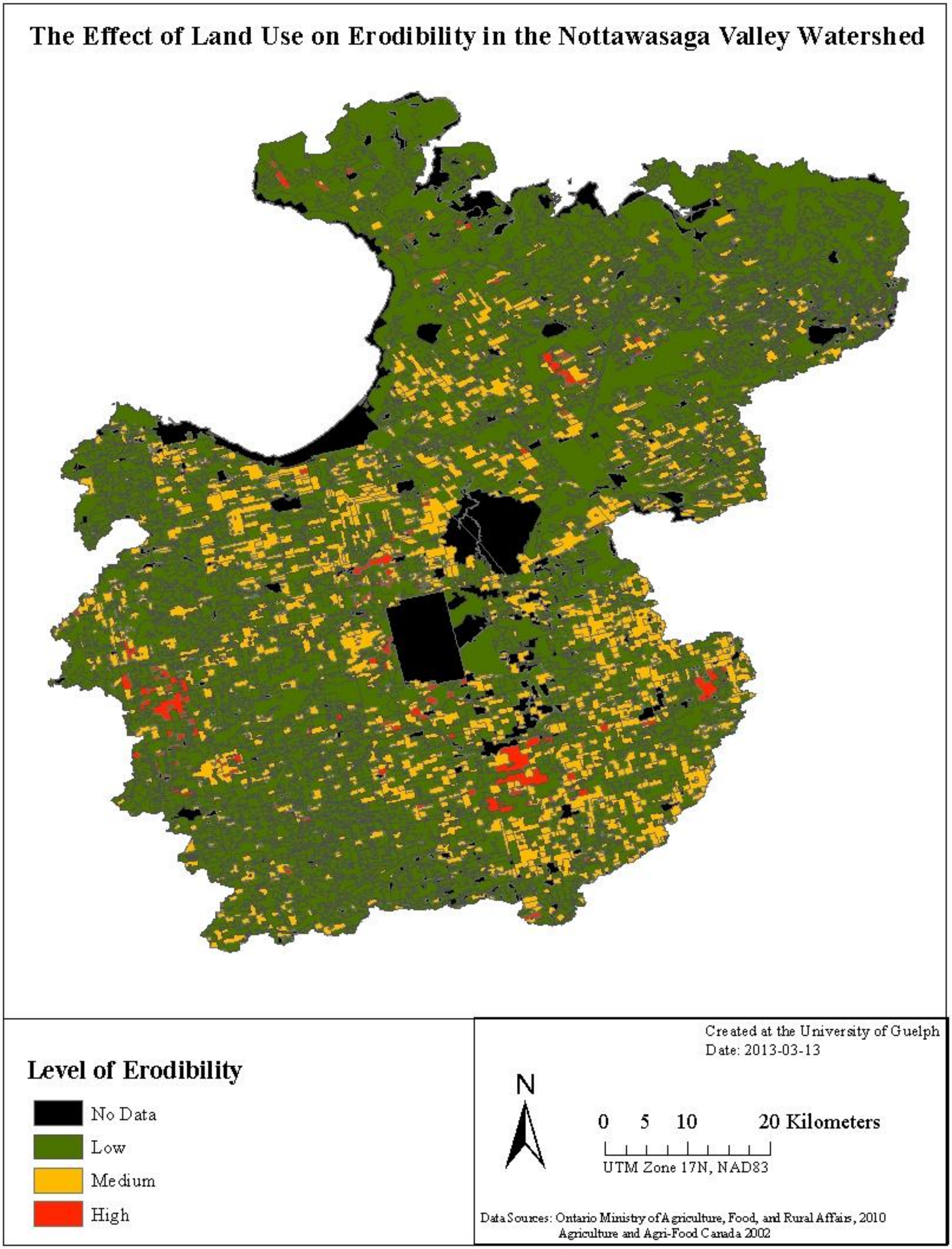

Figure 6.9: A GIS analysis of the effect of land use on erodibility in the Nottawasaga Valley watershed.

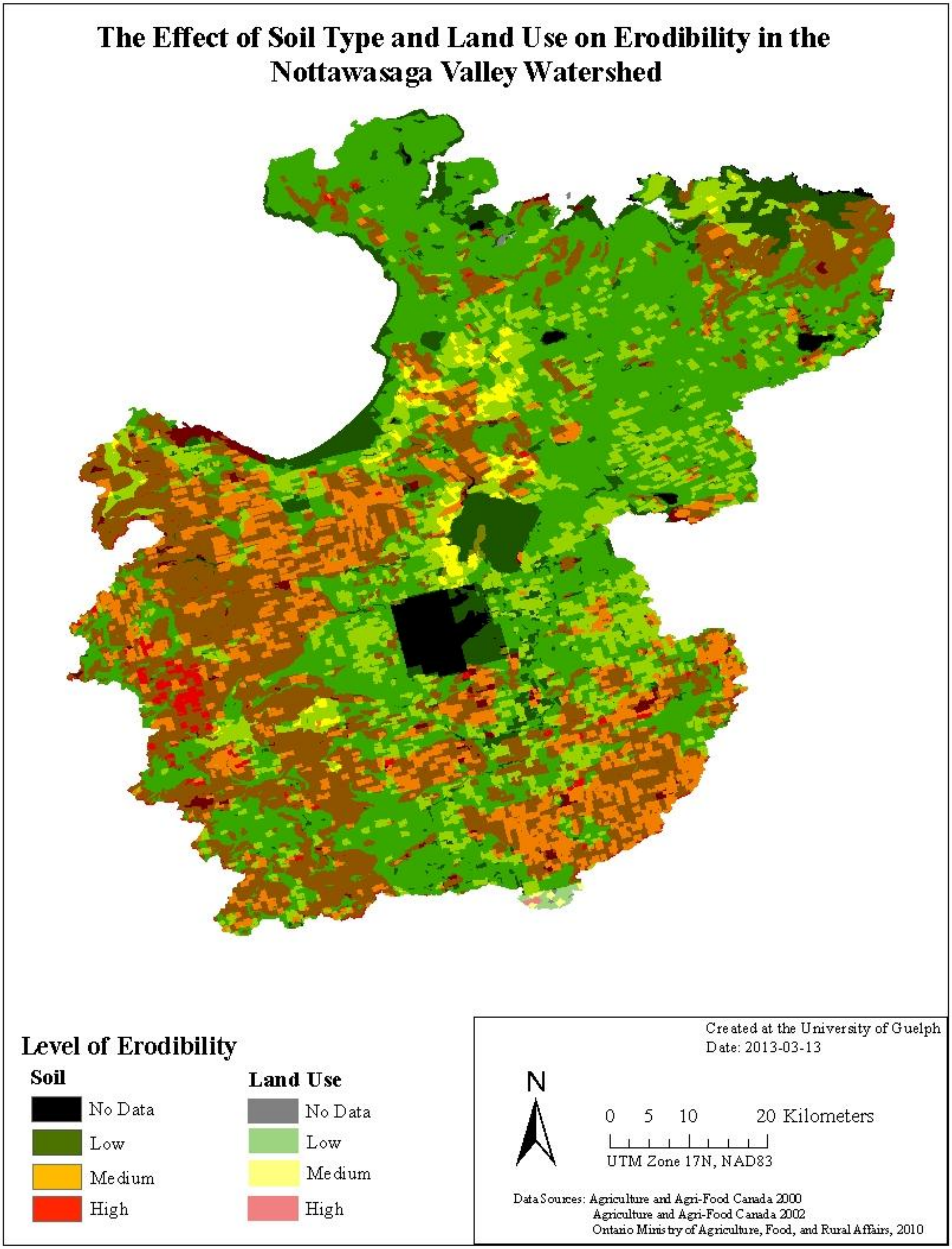

Figure 6.10: A GIS analysis of the effects of both soil type and land use on erodibility in the Nottawasaga Valley watershed.

Figure 6.7 depicts areas of high, medium, and low erodibility based on soil type in the watershed. Figure 6.8 depicts areas of high, medium, and low erodibility based on land cover in the watershed. In both figures 6.7 and 6.8, a red colour represents high erodibility, yellow represents a medium erodibility, green indicates low erodibility, and black indicates no data for that area.

Soil type has the greatest effect on erodibility in the southwest region of the watershed where much of the soil was classified as highly erodible, as seen in figure 6.7. Erodibility was also high in the southeast portion of the watershed, along with a small section in the northeast. Figure 6.8 shows that land use has the greatest effect on erodibility in the center region and as the southeast section of the watershed. Land use practices cause a medium erodibility in these regions, reaching high erodibility in a few small sections. Erodibility is also high in a small section in the southwest region of the watershed. Figure 6.9 represents an overlay of figures 6.7 and 6.8 in order to depict areas that are deemed highly prone to erosion due to the effects of both soil type and land use. The bright red color in figure 6.9 represents areas where erodibility is deemed high due to both soil type and land use. The light brown color represents areas where erodibility due to soil type is high but erodibility due to land use is low. The light orange/brown color represents areas where soil erodibility is high due to soil type and medium due to land cover. Areas that are bright yellow represent medium soil erodibility resulting from both factors. Very light green areas indicate a low erodibility due to soil type and a medium erodibility due to land cover. The medium green color represents areas with low erodibility from both factors.

7.0 Discussion and Recommendations

7.1 Recommendations Based on a Literature Review of Phosphorous Loading

Phosphorus (P) loading continues to be a major environmental issue impacting water quality and long-term ecosystem health within the NVCA watershed and agricultural areas in the region. Windbreaks represent a viable and successful method as they can be applied around terrestrial agricultural areas to mitigate the effects of erosion and P loading. However, windbreaks do not represent the be-all and end-all of management practices and other practices must be considered. An analysis of wind velocity within the NVCA watershed revealed that an optimal placement for windbreaks would be a WSW-ENE orientation. Based on these results, a P loading monitoring project can be recommended for areas within the NVCA watershed that are subject to strong winds from the NNW and SSW direction. This could help determine and measure how much P loading *in addition* to erosion is actually being mitigated by these treed windbreak systems. The location of P 'hot spots' remains difficult to determine due to the spatial variability of deposition rates. Thus, it would be worthwhile to determine deposition rates within the NVCA from both farming and industrial sources. This can provide a platform for further windbreak placement within other agricultural areas or even urban areas.

7.2 Recommendations Based on a Literature Review of the Revised Wind Erosion Equation (RWEQ)

A literature review of the Revised Wind Erosion Equation (RWEQ) revealed that, although factors such as soil type and weather cannot be controlled, levels of wind erosion could be altered with effective land management practices. The RWEQ is a beneficial tool that allows users to see the potential impact of changing their management practices. As noted in the model overview, a 30% residue cover could reduce soil loss by up to 70%, compared to a bare field (Lyon and Smith 2010). The most effective measures landowners can take to prevent wind erosion include keeping the soil covered, planting cover crops and minimizing tillage. Based on the RWEQ review, future studies should address the topography (including slope) of the area under study and include a more comprehensive analysis of various soil characteristics (i.e.

erodible fraction of soil, soil roughness and soil crust). Ideally, there would eventually exist a large enough body of data to apply a computer model to the area in order to quantify the amount of soil erosion occurring in the Nottawasaga Valley watershed.

7.3 Recommendations Based on GIS Analysis

Figure 6.7 outlines areas of high, medium, and low erodibility based on soil type within the NVCA watershed. The areas of the watershed represented by the red colors indicate areas of high erodibility due to soil type. Highly erodible soil types found in these areas include: very fine sand, loamy very fine sand, soil loam, and loam. The majority of the highly erodible land due to soil type is found in the southwest area of the watershed and extends inward toward the center of the region. There is also a significant section of highly erodible land caused by soil type in the south end of the watershed again extending slightly north into the center of the watershed. There are a few small areas of highly erodible land in the northeast corner of the watershed as well. There are a few areas of medium erodibility due to soil type dispersed throughout the region. Soil types included in this medium erodibility class include: clay loam, silty clay, clay, sandy clay loam, and fine sandy loam. The remainder of the watershed was deemed to have low erodibility caused by soil type and this was represented by the green colour. Soils types that are classified in the low erodibility category include: sandy loam, loamy fine sand, fine sand, coarse sandy loam, loamy sand, and sand.

Figure 6.8 outlines areas of high, medium, and low erodibility based on land cover and land use type. Red, yellow, and green are again used to represent areas of high, medium, and low erodibility respectively. There were only a few small areas in the watershed that were classified as highly erodible due to land cover. These areas are found in the south end of the watershed as well as in the southwest and northeast regions. There is also a small area of high erodibility in the center of the watershed, just above the CFB Borden military base. Land cover types in these areas include: extraction of topsoil removal, extensive field vegetables, tobacco systems, grain systems, and continuous row crops. There are numerous areas of medium erodibility due to land cover and land use, which are dispersed throughout the watershed. These areas are most concentrated toward the center of the watershed but also extend outwards to the southeast, northeast and west sections. Land covers associated with a medium erodibility include: orchards, corn systems, mixed systems, berries, and nurseries. The remainder, and majority, of the watershed is classified as low erodibility due to land uses. These land uses included: idle agricultural land, sod farms, pasture systems, grazing systems, hay systems, pastured woodland, woodland, reforestation, recreation, and swamps, bogs and marshes.

Figure 6.9 is an overlay of figures 6.7 and 6.8 and shows land cover with a 40% transparency in order to see the underlying effects of soil type on erodibility. This map depicts areas of concern by taking into account both soil type and land cover. Areas that have the highest erodibility based on these factors are in the southwest, south, and northeast sections of the watershed. There are some areas in the southwest section of the watershed that are classified as highly erodible due to both soil type and land cover which are represented by a bright colour (due to the overlap of red areas from figures 6.7 and 6.8). These are areas of primary concern in the watershed. Another area of concern is in the south section of the watershed where erodibility due to soil type is high and erodibility due to land use is medium (overlap of these yields a light orange/brown colour).

It is recommended that areas which show high or medium erodibility due to both land cover and soil type be the primary focus when deciding on windbreak location within the watershed. These areas need to be protected as soil type and land practices may contribute to high levels of wind erosion in the area. Areas of concern are dominated by agricultural land use. Although tillage practices are unknown for each section or specific field within the watershed, efforts should be focused to encourage the use of conservation tillage in these areas that are highly susceptible to erosion. Another focus should be areas of high erodibility that are in close proximity to water bodies as sediment transport from farmers' fields may have detrimental effects if deposited in water bodies. The use of windbreaks in these areas of high erodibility could contribute to the mitigation of wind erosion of the various soil types in the watershed and could reduce sediment transport (and therefore P transport) into water bodies within and surrounding the watershed.

7.4 Recommendations for Orientation, Location and Placement of Windbreaks

From our analysis of wind velocity we have concluded that windbreaks should be oriented perpendicular to the most dominant winds in order to best mitigate soil erosion. In this case, windbreaks should thus be oriented in a WSW-ENE direction as the predominant winds come from a NNW and SSW direction. They should also be oriented around the most vulnerable soils, which are highlighted on the GIS maps in red.

Results from our wind rose diagrams show that winds in the summer months tend to be less strong. They are predominantly around 5-15 km/h and come from a NW direction with a bit of wind coming from the S at a 5-10 km/h speed. Wind in the spring months, from March to May, tends to have a greater proportion of higher winds ranging from 16-20 km/h that are also from a NW-NNW direction (with some SE winds). The spring months also tended to be gustier. Wind in October appeared to be more scattered with heavier winds like in the spring, but the wind was still coming from a NNW and SE direction. Winter months showed winds at a 10-20 km/h range with a greater proportion of heavier winds ranging from 20-30 km/h. Examination of winds in excess of 30 km/hr further demonstrated the need for windbreak orientation in a WSW-ENE direction in order to best mitigate the soil-eroding effects of these winds.

The analysis of precipitation data revealed a general trend where December and January were typically the driest months and June and July were the wettest months (with a few anomalies). This information is key for assessing the time of year when highly erodible areas have an increased susceptibility to wind erosion due to a lack of soil moisture. However, snow cover and snowmelt were not considered in this investigation as they were beyond the scope of this undergraduate research project. These factors could have a significant impact on a soil's susceptibility to erosion because of their influence on soil moisture. The interpretation of when the soils in the Nottawasaga Valley watershed are dry and when they are wet was thus limited to rainfall data analyses, which typically showed an increased amount of rainfall in the summer months of June and July.

7.5 General Recommendations

Aside from the possibility of mitigating P loading, there are various other reasons why a landowner would be interested in installing windbreaks on their farm. The benefits of windbreaks on individual fields are numerous- not only will windbreaks prevent soil from leaving the field, but they serve other purposes as well. Ancillary benefits include odour control, home and barn protection from snow, reduced energy costs for the homestead, habitat for birds and animals and additions to the aesthetics of the landscape (LRC and UofT 1994; Current et al. 1995; Brandle et al. 2004). Therefore, although windbreaks might be initially expensive, they provide numerous benefits for the farmers in the long run.

This avenue of P loading research is warranted, especially since the public remains largely uninformed and doubtful of the progress that stewardship initiatives are having for the area. The many stewardship programs in place for the area should aim to become more transparent and better highlight their progress and achievements. Media releases of studies such as the one at hand can provide knowledge and guidance for farmers and thus should be made available for public access. Windbreaks represent a viable better management practice for the NVCA watershed, but the significant reduction of erosion and P loading cannot be achieved without outreach programs targeted at the education of both farmers and the public regarding these issues.

7.6 Future Directions

Wind-borne erosion of agricultural soils around Lake Simcoe continues to be an issue for farmers. The analysis of wind velocity and soil properties within the NVCA watershed revealed which soils and areas are most susceptible to wind erosion and thus would benefit from the use of windbreaks. The study at hand can be further extended to determine how efficiently windbreaks mitigate P loading in addition to erosion. Future studies should continue to focus on high value agricultural soils. This would not only provide viable soil erosion data, but would entice more farmers to incorporate windbreaks around their land. Windbreak placement can prove beneficial for soil conditions and for improving water quality, which continues to decrease due to a host of anthropogenic factors. An extension of the study at hand would involve erosion and P loading monitoring coupled with an analysis of the effects of windbreak placement on aquatic health and water quality.

While this study provides a valuable knowledge base regarding wind-driven soil erosion in the Nottawasaga Valley watershed, there do exist certain research limitations that could be improved upon through further exploration. In particular, further research should incorporate precipitation and wind data from a larger number of weather stations (i.e. more locations within the watershed) in order to achieve a more complete and comprehensive data analysis. Precipitation and wind data analyses could also be improved by considering data over a longer time scale. In addition, it would be beneficial to further investigate the impact of snow cover and snowmelt (and other associated soil moisture factors) on the susceptibility of soils to wind erosion.

Future studies of a similar nature or those expanding upon our results should be equipped with better soil and field databases of the watershed. This information could then be used in software like WEPS and SWEEP to quantify the wind erosion of soil occurring in this area. This would require someone visiting the various locations and collecting the appropriate data. At the time of this study, the information necessary to run the software was not readily accessible. Thus, further research should focus on the use of a mathematical model for the prediction and estimation of erosion within a selected area. This would require better access to the data necessary for calculations and a familiarity with computer programs such as WEPS or SWEEP. While the proper calculation and interpretation of the mathematical results of such a model were beyond the scope of this 8-month undergraduate project, this type of wind erosion model represents a worthwhile avenue of investigation for future projects.

In the future, the GIS analysis could incorporate data for each of the factors of the WEPS or SWEEP model. This would provide a more accurate depiction of the potential for erosion on a field-by-field basis. Once each of the components of a model such as WEPS or SWEEP are determined, separate GIS layers could be used to represent each of the variables and subsequently overlaid to calculate the erodibility of a particular field. Again, data would need to be collected on a field-by-field basis. However, this approach may be of interest after highlighting the areas of the Nottawasaga Valley watershed that are particularly prone to erosion, which was accomplished in this study. It would be beneficial to target specific fields with a high probability of erosion, and analyze these areas at a larger scale in order to obtain a higher level of detail in the GIS maps.

Finally, future research could apply this study's methods of investigation to other areas that are experiencing issues with wind erosion or nutrient transport (i.e. P loading). While every area is unique and will present new and diverse challenges, the fundamental analysis presented in this study can be applied to different regions to determine areas of high susceptibility to wind erosion.

8.0 Conclusions

Currently, there is a need for the proper management of the factors that affect wind erosion in the Nottawasaga Valley watershed. Wind erosion and phosphorus loading are a major concern for this area, especially as extensive farming continues throughout the watershed. Windbreak systems represent a viable management strategy that can be used in this area to partly alleviate the negative environmental impacts that are resulting from wind erosion (i.e. phosphorus loading). Precipitation and wind data were analyzed for the Nottawasaga Valley watershed along with soil type and land use, which were included in GIS analysis. The production of numerous wind rose diagrams along with GIS analysis incorporating soil erodibility factors provided viable results for discussion. Recommendations for windbreak placement within the watershed were determined by taking all analyses into account. These windbreak systems should thus be promoted as viable 'best management practices' in the mitigation of wind erosion and P loading. By taking into consideration the characteristics of the Nottawasaga Valley watershed and the results of this study, windbreaks should be considered as a worthwhile long-term investment for farmers in the NVCA region. Further studies could address the limitations of this research project to increase the public's understanding of windbreaks and their potential to mitigate phosphorus loading.

9.0 References

[AAFC] Agriculture and Agri-Food Canada. 2002. Revised universal soil loss equation for application in Canada: a handbook for estimating soil loss from water erosion in Canada [Internet]. Ottawa (ON); [cited 2013 Mar 13]; [117 pages]. Available from: http://sis.agr.gc.ca/cansis/publications/manuals/2002-92/rusle-can.pdf

[AAFC] Agriculture and Agri-Food Canada. 2012. Wind erosion [Internet]. Ottawa (ON); [updated 2012 Aug 14; cited 2013 Mar 6]; [1 screen]. Available from: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1187288822483&lang=eng

Anderson KA, Downing JA. 2006. Dry and wet atmospheric deposition of nitrogen, phosphorous and silicon in an agricultural region. Water, Air, and Soil Pollution (176) [Internet]. [cited 2012 Nov 17]; 176: 351-374. Available from: http://link.springer.com/article/10.1007%2Fs11270-006-9172-4?LI=true doi: 10.1007/s11270-006-9172-4

Armstrong, D.K. 2000. Paleozoic geology of the northern Lake Simcoe area, South-Central Ontario (ON); [cited 2013 Mar 15]; [57 pages]. Available from: http://www.geologyontario.mndmf.gov.on.ca/mndmfiles/pub/data/imaging/OFR6011/OFR6011.pdf

Bagnold RA. 1941. The physics of blown sand and desert dunes. London: Methuen. 265 p.

Bilbro JD, Fryrear DW. 1994. Wind erosion losses as related to plant silhouette and soil cover. Agronomy Journal [Internet]. [cited 2013 Mar 6]; 86(3): 550-553. Available from: https://www.crops.org/publications/aj/abstracts/86/3/AJ0860030550?access=0&view=pdf

Blanco H, Lal R. 2010. Principles of soil conservation and management. New York (NY): Springer. 617 p.

Brandle JR, Hodges L, Zhou XH. 2004. Windbreaks in North American agricultural systems. Agroforestry Systems [Internet]. [cited 2012 Nov19]; 61-62(1-3): 65-78. Available from: http://link.springer.com/article/10.1023/B:AGFO.0000028990.31801.62

Brown LJ, Taleban V, Gharabaghi B, Weiss L. 2011. Seasonal and spatial distribution patterns of atmospheric phosphorus deposition to Lake Simcoe, ON. Journal of Great Lakes Research [Internet].[cited 2012 Nov 17]; 37(3):15-25. Available from: http://www.sciencedirect.com/science/article/pii/S0380133011000062

Buschiazzo DE, Zobeck TM. 2008. Validation of WEQ, RWEQ and WEPS wind erosion for different arable land management systems in the Argentinean Pampas. Earth Surface Processes and Landforms [Internet]. [cited 2013 Mar 5]; 33:1839–1850. Available from: http://naldc.nal.usda.gov/download/27867/PDF

Cebecauer T, Hofierka J. 2008. The consequences of land-cover changes on soil erosion distribution in Slovakia. Geomorphology [Internet]. [cited 2012 Nov19]; 98: 187-198. Available from: http://www.sciencedirect.com/science/article/pii/S0169555X07002231

Chepil WS. 1945. Dynamics of wind erosion: III- the transport capacity of the wind. Soil Science [Internet]. [cited 2013 Mar 5]; 60(6):475-480. Available from: http://journals.lww.com/soilsci/Citation/1945/12000/Dynamics_of_Wind_Erosion__III__the_Transport.6.aspx

Chepil WS. 1957. Width of field strips to control wind erosion. Volume 92 of technical bulletin (Kansas Agricultural Experiment Station). Agricultural Experiment Station, Kansas State College of Agriculture and Applied Science. 16 p.

Cleugh HA. 1998. Effects of windbreaks on airflow, microclimates and crop yields. Agroforestry Systems [Internet]. [cited 2012 Nov19]; 41: 55-84. Available from: http://link.springer.com/article/10.1023/A:1006019805109

Cornelis WM, Gabriels D, Hartmann R. 2004. A parameterisation for the threshold shear velocity to initiate deflation of dry and wet sediment. Geomorphology [Internet]. [cited 2013 Feb 14]; 59(1-4):43-51. Available from: http://www.sciencedirect.com/science/article/pii/S0169555X0300312X

Egbai OO, Ndik EJ, Ogogo AU. 2012. Influence of soil textural properties and land use cover type on soil erosion of a characteristic Ultisols in Betem, Cross River Sate, Nigeria. Journal of Sustainable Development. 5(7): 104-110.

Environment Canada. 2012. National climate data and information archive: Barrie WPCC station results [Internet]. [cited 2013 Feb 7] Available from: http://www.climate.weatheroffice.gc.ca/climate_normals/results_e.html?stnID=4408&lang=e&dCode=0&province=ONT&provBut=Search&month1=0&month2=12

Environment Canada. 2013a. National climate data and information archive: hourly data report [Internet]. [cited 2013 Mar 14]. Available from: http://www.climate.weatheroffice.gc.ca/climateData/hourlydata_e.html?timeframe=1&Prov=ONT&StationID=27604&hlyRange=2000-08-18%7C2012-10-21&Month=1&Day=1&Year=2008&cmdB2=Go

Environment Canada. 2013b. National climate data and information archive: daily data report [Internet]. [cited 2013 Mar 14]. Available from: http://www.climate.weatheroffice.gc.ca/climateData/dailydata_e.html?timeframe=2&Prov=ONT&StationID=27604&dlyRange=2000-08-17|2013-03-16&Month=1&Year=2008&cmdB1=Go&Day=17

Evans DO, Nicholls KH, Allen YC, McMurtry MJ. 1996. Historical land use, phosphorus loading, and loss of fish habitat in Lake Simcoe, Canada. Canadian Journal of Fisheries and Aquatic Sciences [Internet]. [cited 2012 Nov 13]; 53:194-218. Available from: http://www.nrcresearchpress.com/doi/abs/10.1139/f96-012#.UGsKKVEdzYg

Fryrear DW, Saleh A. 1996. Wind erosion: field length. Soil Science [Internet]. [cited 2013 Mar 5];161(6):398-404. Available from: http://journals.lww.com/soilsci/toc/1996/06000

Fryrear DW, Sutherland PL, Davis G, Hardee G, Dollar M. 2001.Wind erosion estimates with RWEQ and WEQ. Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting [Internet]. [cited 2013 March 5];760-765. Available from: http://topsoil.nserl.purdue.edu/nserlweb-old/isco99/pdf/ISCOdisc/SustainingTheGlobalFarm/P120-Fryrear.pdf

Gamble, T. 1997. Environment Canada: the Canada country study - Ontario region executive summary [Internet].[cited 2013 Feb 7]; [about 4 screens]. Available from: http://www.on.ec.gc.ca/canada-country-study/intro.html

Government of Ontario. 2009. Lake Simcoe Protection Plan. Ontario; [cited 2012 Nov 17]; [45 pages]. Available from: http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_076302.pdf

Hoffman DW, Wicklund RE, Richards NR. 1962. Soil Survey of Simcoe County Ontario: Report No. 29 of the Ontario Soil Survey. Ottawa: Canada Department of Agriculture and Toronto: Ontario Agriculture College. 110 p.

Li XY, Liu LY, Wang JH. 2004. Wind tunnel simulation of aeolian sandy soil erodibility under human disturbance. Geomorphology [Internet]. [cited 2012 Nov 18]; 59(1-4):3–11. Available from: http://adrem.org.cn/Faculty/LiuLY/paper/2004-lxy-Geomorphology-.pdf

[LRC and UofT] Land Owner Resource Centre and University of Toronto Faculty of Forestry. 1994. Extension Notes: The benefits of windbreaks [Internet]. Toronto, (ON); [cited 2012 Nov 13]; [4 pages]. Available from: http://www.lrconline.com/Extension_Notes_English/pdf/wndbrk_bnfts.pdf

[LSRCA] Lake Simcoe Region Conservation Authority. 2006. Assimilative capacity studies: Final report – Chapter 3: Nottawasaga Valley Conservation Authority [Internet]. Newmarket

(ON); [cited 2013 Feb.4]; [134 pages]. Available from: http://www.lsrca.on.ca/pdf/reports/acs/berger_target_chapter_3.pdf

[LSRCA] Lake Simcoe Region Conservation Authority. 2008. Watershed Report Card 2008: A report on the health of the Lake Simcoe watershed [Internet]; [cited 2012 Nov 13]; [24 pages]; Available from: http://www.lsrca.on.ca/reports/

[LSRCA] Lake Simcoe Region Conservation Authority. 2012. Lake Simcoe science: aquatic plants [Internet] Newmarket, ON; [cited 2013 Feb 5]; [4 pages]. Available from: http://www.lsrca.on.ca/pdf/reports/newsletter/LSScience_newsletter_june2012.pdf

[LSRCA] Lake Simcoe Region Conservation Authority. 2013. Nottawasaga Valley source protection area. Drinking water source protection [Internet]. Newmarket (ON); [cited 2013 Jan 28]; [about 3 screens]. Available from: http://www.ourwatershed.ca/sgb/watersheds/nvca.php

[LSSAC] Lake Simcoe Science Advisory Committee. 2008. Lake Simcoe and its watershed – Report to the Ministry of the Environment [Internet]. [cited 2012 Nov 17]; [116 pages]. Available from: http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/stdprod_078249.pdf

Lyon DJ, Smith JA. 2010. NebGuide: Wind erosion and its control. Lincoln (NE): University of Nebraska-Lincoln Extension, Institute of Agriculture and Natural Resources; [updated 2010 Mar; cited 2013 Mar 5]. Available from: http://www.ianrpubs.unl.edu/pages/publicationD.jsp?publicationId=130

MacLaren Plansearch Inc. 1988. Watershed hydrology study for Nottawasaga, Pretty and Batteaux rivers, Black Ash, Silver and Sturgeon creeks [Internet]. Willowdale (ON); [cited 2013 Jan 28]; [180 pages]. Available from: http://www.nvca.on.ca/OurProgramsandServices/EngineeringTechnicalServices/Library/index.htm

Maharani YN, Lee S, Lee Y. 2009. Topographical effects on wind speed over various terrains: a case study for Korean Peninsula. The Seventh Asia-Pacific Conference on Wind Engineering; Taipei (Taiwan); [cited 2013 Mar 5]; 11 p. Available from: http://www.iawe.org/Proceedings/7APCWE/T2D_5.pdf

McCauley A, Jones C. 2005. Soil and Water Management Module 3: Managing for Soil Erosion. Montana: Montana State University. 10p.

[MOE] Ministry of Environment. 2012. Nottawasaga Valley source protection area approved assessment report – Chapter 3: Water budget and water quantity risk assessment. Ontario; [cited 2013 Mar 15]; [188 pages]. Available from: http://www.ourwatershed.ca/assets/files/assessmentreport/nottawasagavalley_ch3_waterbudget.pdf

Morales-Baquero R, Pulido-Villena E, Reche I. 2006. Atmospheric inputs of phosphorus and nitrogen to the southwest Mediterranean region: Biogeochemical responses of high mountain lakes. Limnology and Oceanography [Internet]. [cited 2012 Nov 17]; 51(2): 830-837. Available from: http://aslo.orgwww.aslo.org/lo/toc/vol_51/issue_2/0830.pdf

Moreno RG, Requejo AS, Altisent JMD, Alvarez MCD. 2011. Significance of soil erosion on soil surface roughness decay after tillage operations. Soil & Tillage Research [Internet]. [cited 2013 Mar 2]; 117:49-54. Available from: http://www.sciencedirect.com/science/article/pii/S0167198711001401

Nordstrom KF, Hotta S. 2004. Wind erosion from cropland in the USA: a review of problems, solutions and prospects. Geoderma [Internet]. [cited 2012 Nov 17]; 121:157–167. Available from: http://isites.harvard.edu/fs/docs/icb.topic117334.files/Dust_Geoderma.pdf

[NVCA] Nottawasaga Valley Conservation Authority. 2005. NVCA watershed management plan [Internet]. Utopia (ON); [cited 2013 Feb 4]; [117 pages]. Available from:

http://www.nvca.on.ca/ws_par/groups/public/@pub/@nvca/documents/web_content/wspar_009528.pdf

[NVCA] Nottawasaga Valley Conservation Authority. 2006a. NVCA watershed report cards: a summary of watershed health [Internet] ON; [cited 2013 Feb 5]; [1 page]. Available from: http://www.nvca.on.ca/ourprogramsandservices/watershedmonitoring/

[NVCA] Nottawasaga Valley Conservation Authority. 2006b. NVCA development review guidelines [Internet]. [cited 2013 Feb 5]; [57 pages]. Available from: http://nvca.on.ca/ws_par/groups/public/@pub/@nvca/documents/web_content/wspar_009444.pdf

[NVCA] Nottawasaga Valley Conservation Authority. 2007a. 2007 watershed report card [Internet]. ON; [cited 2013 Feb 5]; [4 pages]. Available from: http://www.nvca.on.ca/ws_par/groups/public/@pub/@nvca/documents/web_content/wspar_016713.pdf

[NVCA] Nottawasaga Valley Conservation Authority. 2007b. Sub-watershed report cards [Internet]. Utopia (ON); [cited 2013 Jan 28]; [40 pages]. Available from: http://www.nvca.on.ca/ourprogramsandservices/watershedmonitoring/

[NVCA/OMAFRA] Nottawasaga Valley Conservation Authority and Ontario Ministry of Agriculture, Food and Rural Affairs. 2012. Multifunctional windbreaks: design options and economic evaluation. [Internet]. Utopia (ON); [cited 2013 Jan 28]. Available from: http://nvca.on.ca/ws_par/groups/public/@pub/@nvca/documents/web_content/wspar_039641.pdf

[OMAFRA] Ontario Ministry of Agriculture, Food and Rural Affairs. 1994. Best management practices: soil management. Toronto (ON): Ontario Federation of Agriculture. 68 p.

Ramkellawan J, Gharabaghi B, Winter JG. 2009. Application of Weather Radar in Estimation of Bulk Atmospheric Deposition of Total Phosphorous Over Lake Simcoe. Canadian Water Resources Journal [Internet]. [cited 2012 Nov 13]; 34(1):37-60. Available from: http://pubs.cwra.org/doi/abs/10.4296/cwrj3401037 doi: 10.4296/cwrj3401037

Ravi S, Zobeck TM, Over TM, Okin GS, D'Odorico P. 2006. On the effect of moisture bonding forces in air-dry soils on threshold friction velocity of wind erosion. Sedimentology. 53:597-609.

Sharma A, Tiwari KN, Bhadoria PBS. 2011. Effect of land use land cover change on soil erosion potential in an agricultural watershed. Environmental Monitoring and Assessment [Internet]. [cited 2012 Nov 19]; 173(1-4):789–801. Available from: http://www.ncbi.nlm.nih.gov/pubmed/20364312

Sharratt B, Wendling L, Feng G. 2012. Surface characteristics of a windblown soil altered by tillage intensity during summer fallow. Aeolian Research. 5:1-7.

[SPC] South Georgian Bay-Lake Simcoe Source Protection Committee. 2007. Nottawasaga Valley source protection area [Internet]. Newmarket (ON); [cited 2013 Feb 4]. Available from: http://www.ourwatershed.ca/sgb/watersheds/nvca.php

[SPC] South Georgian Bay-Lake Simcoe Source Protection Committee. 2011. Approved assessment report: Nottawasaga Valley source protection area [Internet]. Newmarket (ON); [cited 2013 Feb 4]. Available from: http://www.ourwatershed.ca/assets/files/assessmentreport/nottawasagavalley_frontmaterial.pdf

Tatarko, J. 2004. Wind erosion: processes and control. Oral presentation at the Natural Resource Engineering (BAE530); Biological and Agricultural Engineering, Kansas State University; Manhattan (KS): USDA-ARS Engineering & Wind Erosion Research Unit. 31 p.

Troeh FR, Hobbs JA, Donahue RL. 1999. Soil and water conservation: Productivity and environmental protection. 3rd ed. Upper Saddle River (NJ): Prentice Hall. 610 p.

[USDA] United States Department of Agriculture. No date. [cited 2013 Mar 5]; [14 pages]. Available from: http://www.lbk.ars.usda.gov/wewc/rweq/sec5-2.pdf

Vigiak O, Sterk G, Warren A, Hagen LJ. 2003. Spatial modeling of wind speed around windbreaks. Catena. 52(3-4):273–288.

Webb NP, McGowan HA. 2009. Approaches to modeling land erodibility by wind. Progress in Physical Geography [Internet]. [cited 2013 Mar 5]; 33(5):587-613. Available from: http://journals1.scholarsportal.info.subzero.lib.uoguelph.ca/details-sfx.xqy?uri=/03091333/v33i0005/587_atmlebw.xml

Weinan C, Zhibao D, Zhenshan L, Zuotao Y. 1996. Wind tunnel test of the influence of moisture on the erodibility of loessial sandy loam soils by wind. Journal of Arid Environments [Internet]. [cited 2013 Mar 1]; 34(4):391-402. Available from: http://www.sciencedirect.com/science/article/pii/S0140196396901196

White RE. 1997. Principles and practice of soil science: The soil as a natural resource. 3rd ed. Oxford: John Wiley & Sons. 348 p.

Winter JG, Elmers MC, Dillion PJ, Scott LD, Schelder WA, Willox CC. 2007. Phosphorus Inputs to Lake Simcoe from 1990 to 2003: Declines in Tributary Loads and Observations on Lake Water Quality. Journal of Great Lakes Research (33) [Internet]. [cited 2012 Nov 17]; 33: 381-396. Available from: http://desc.ca/sites/default/files/Articles/Winter%20et%20al_2007.pdf

Zobeck TM. 1991. Soil properties affecting wind erosion. Journal of Soil and Water Conservation [Internet]. [cited 2013 Feb 28]; 46(2): 112-118. Available from: http://www.jswconline.org/content/46/2/112.extract

10.0 Appendix A

10.1 Wind Rose Diagrams

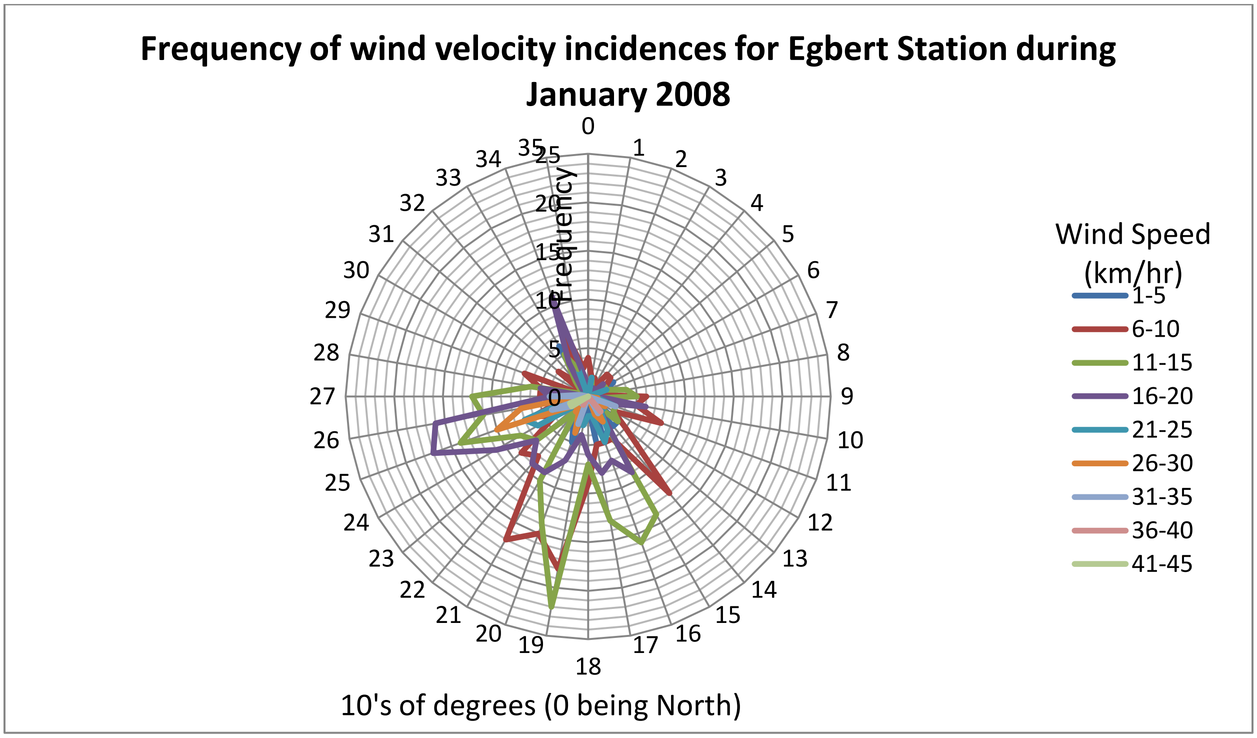

Figure 10.1: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during January 2008.

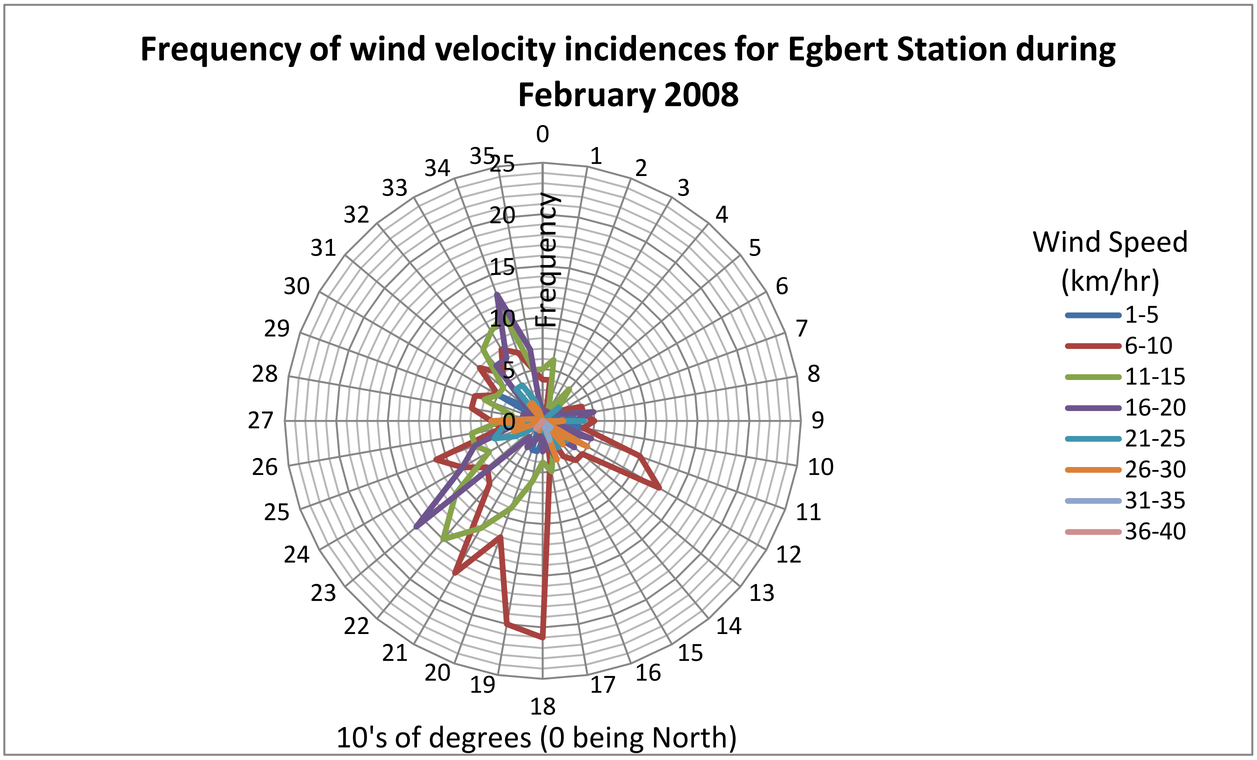

Figure 10.2: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during February 2008.

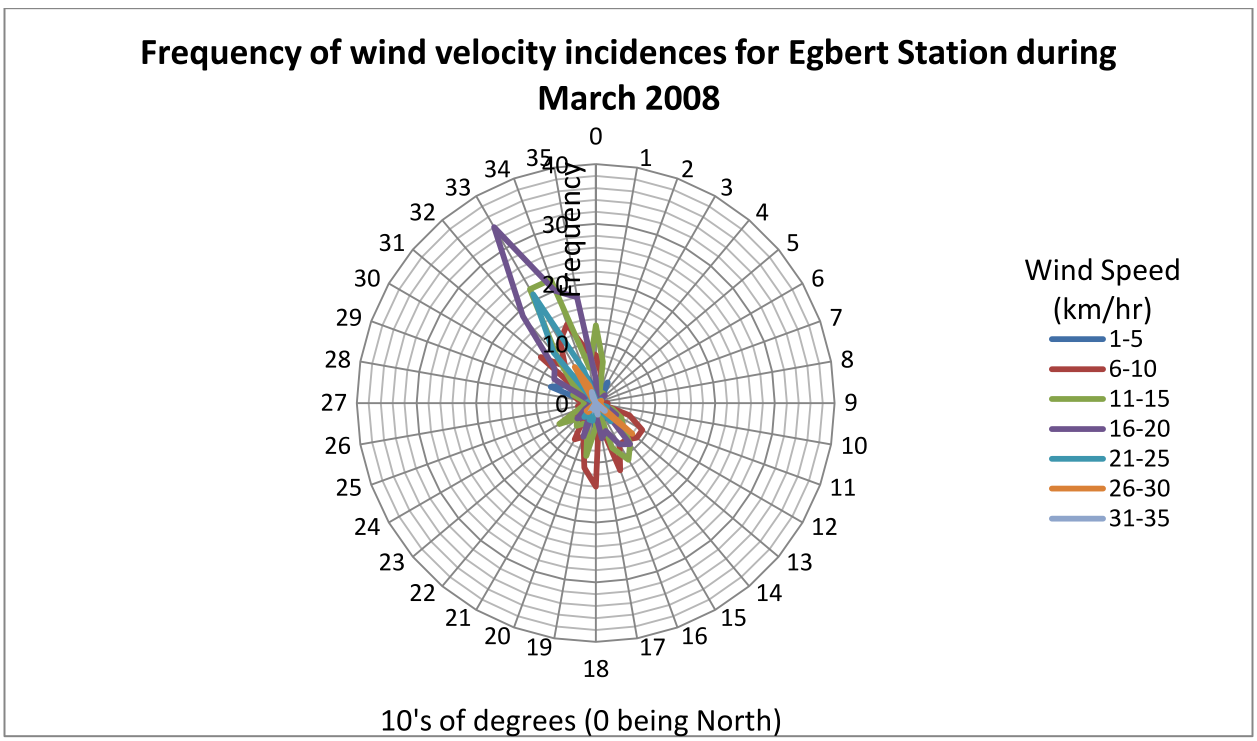

Figure 10.3: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during March 2008.

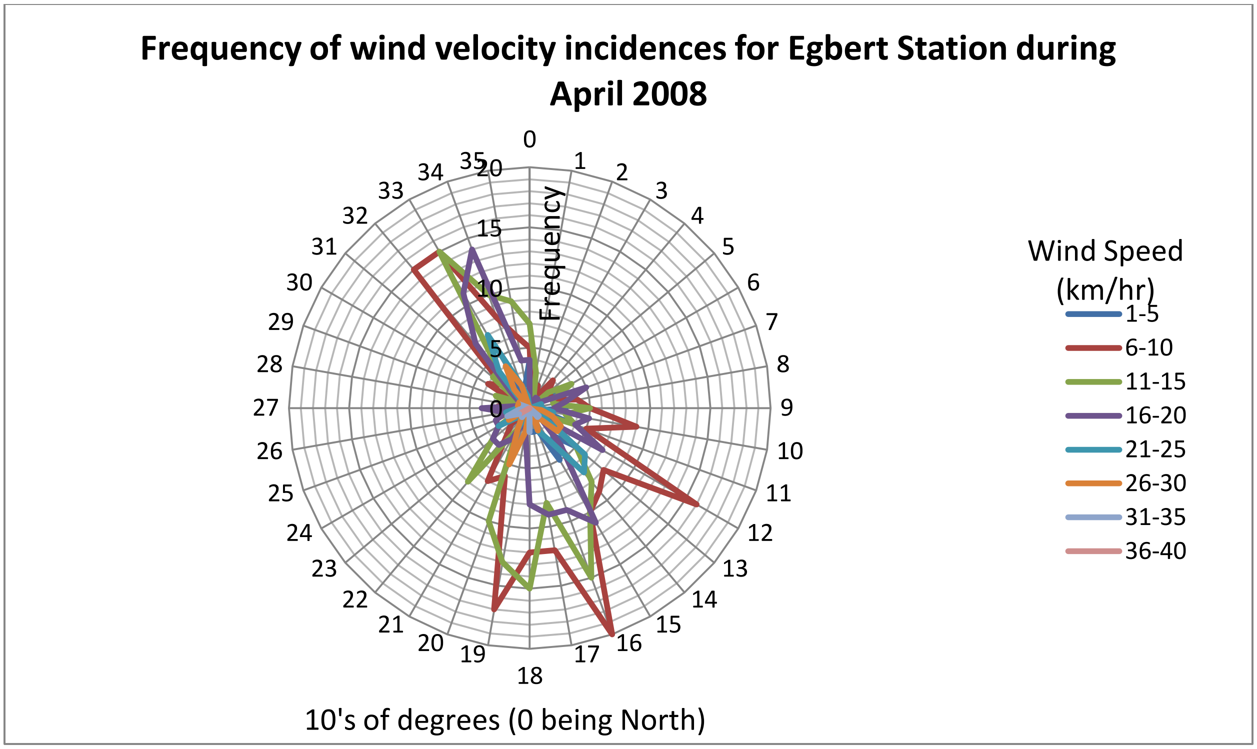

Figure 10.4: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during April 2008.

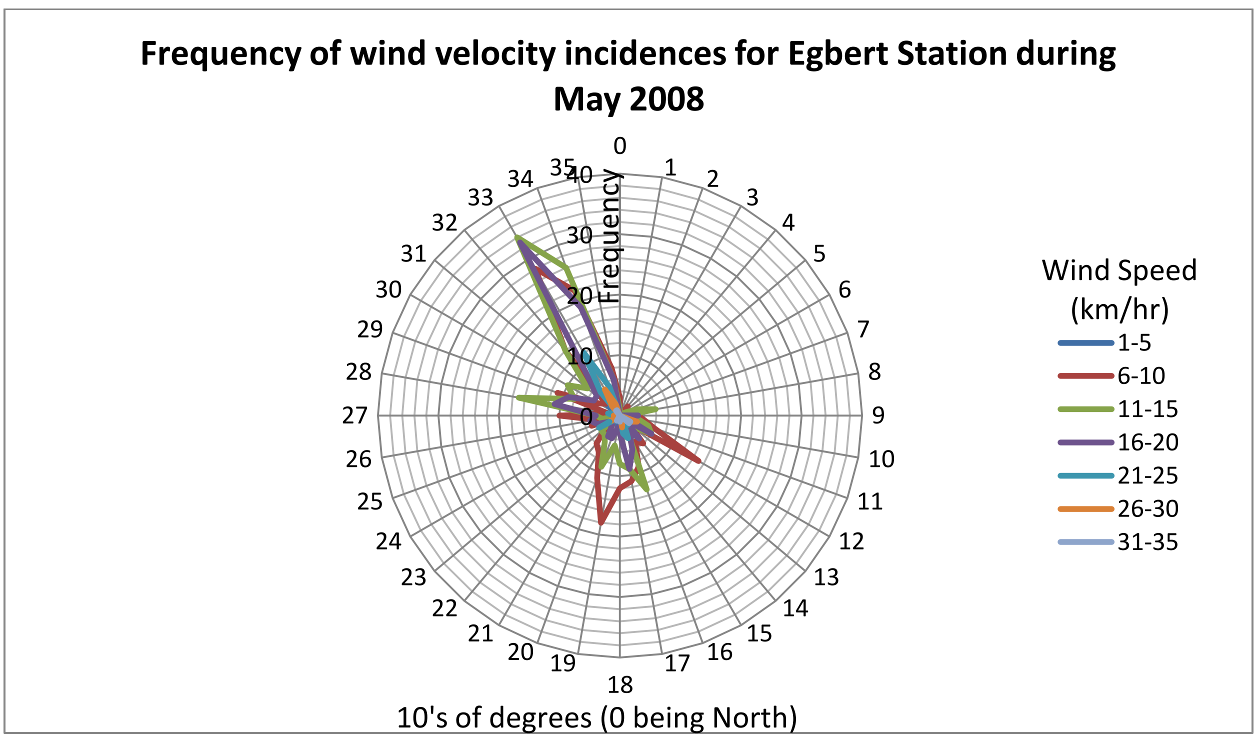

Figure 10.5: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during May 2008.

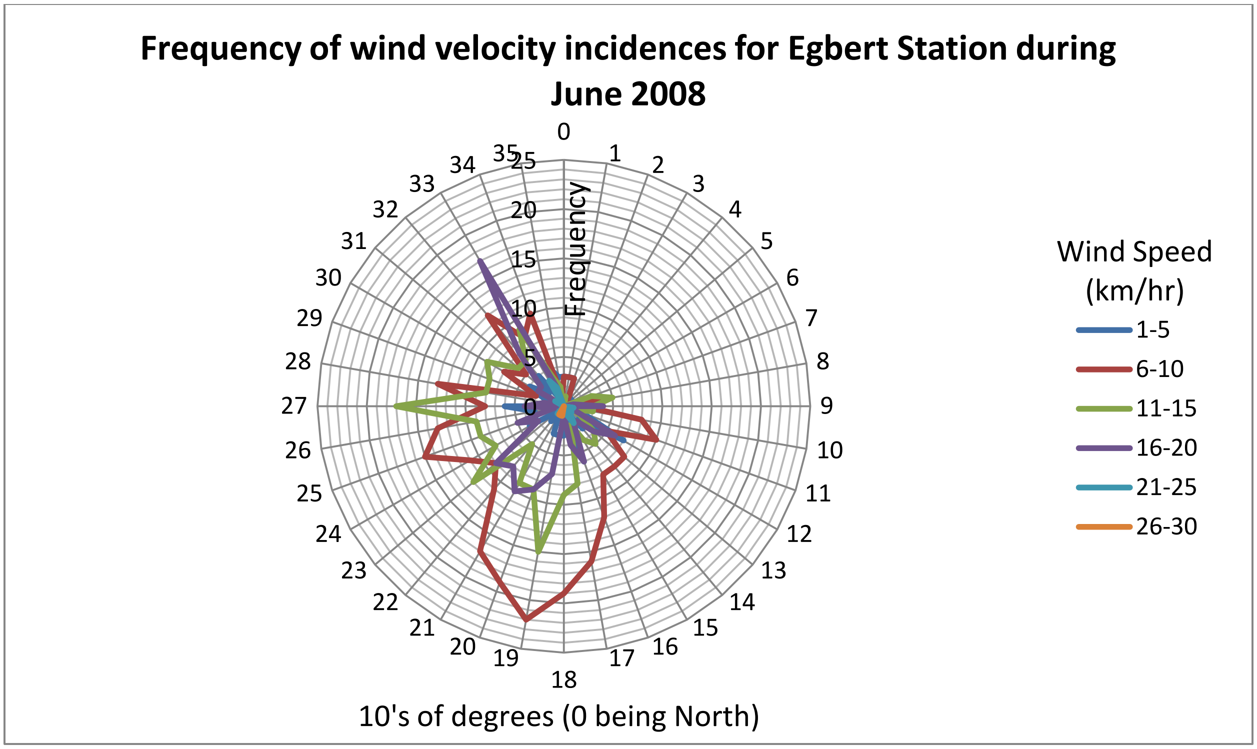

Figure 10.6: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during June 2008.

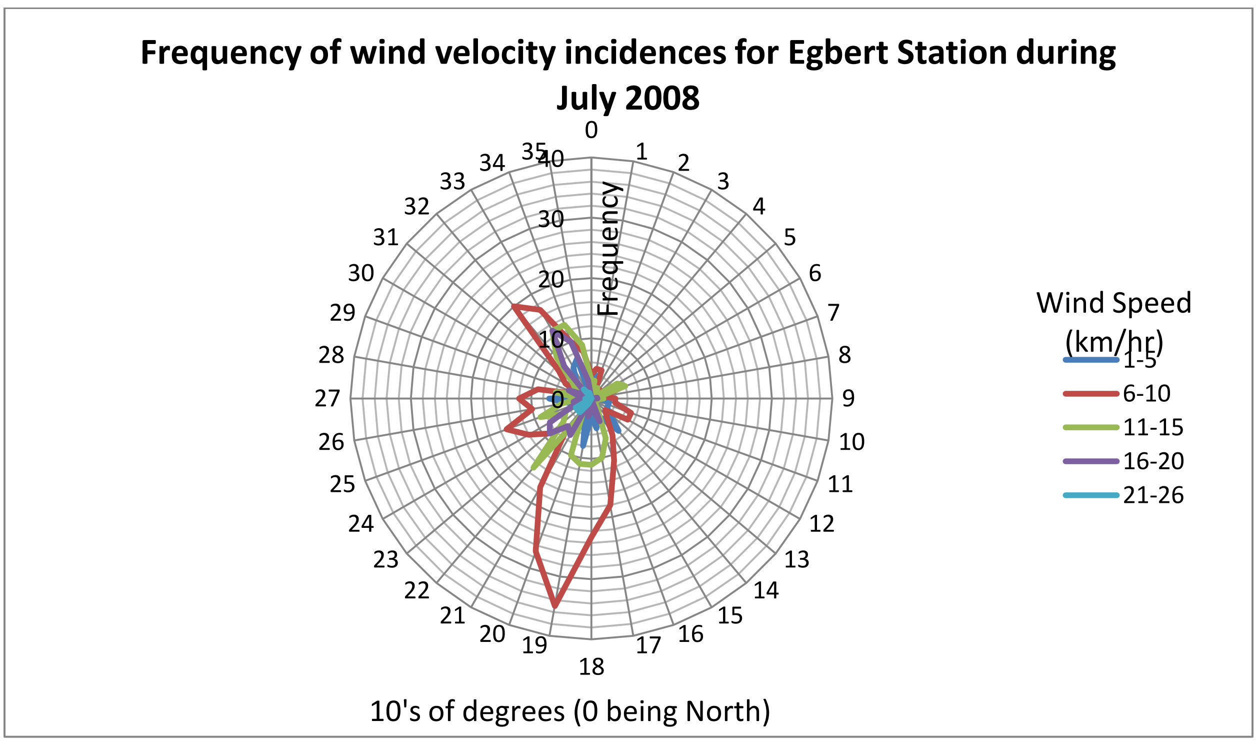

Figure 10.7: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during July 2008.

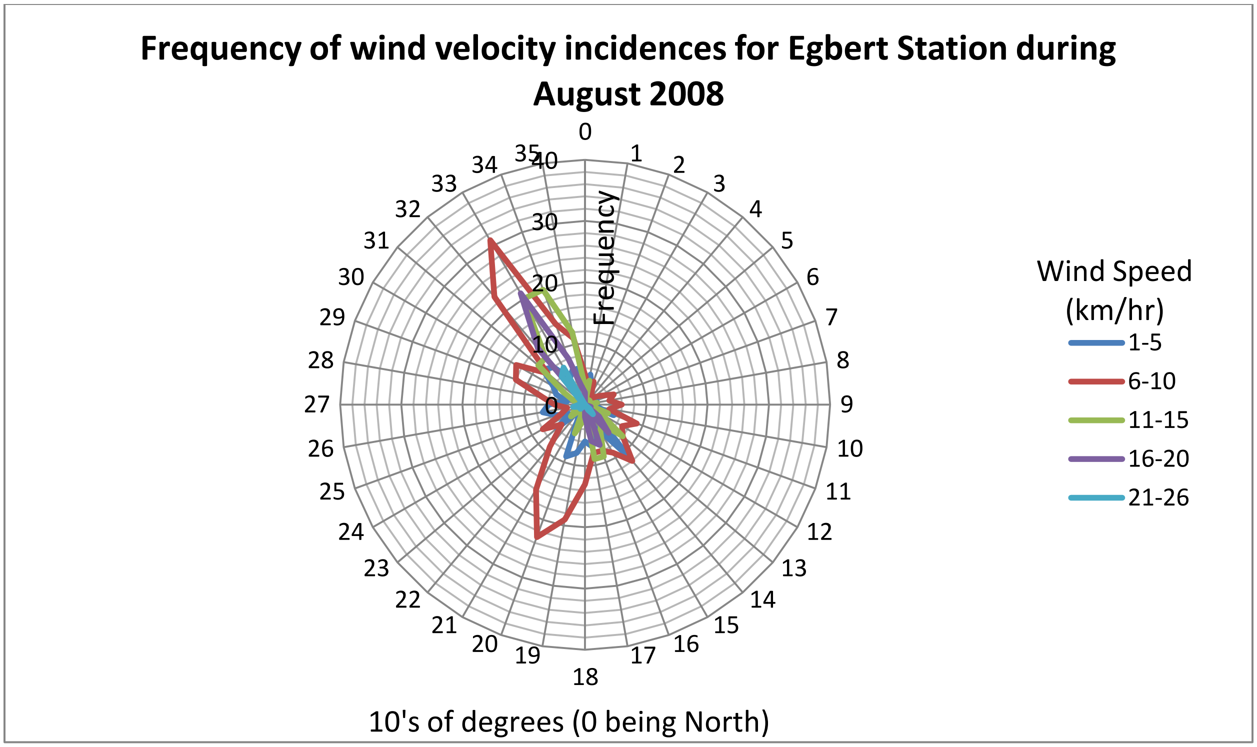

Figure 10.8: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during August 2008.

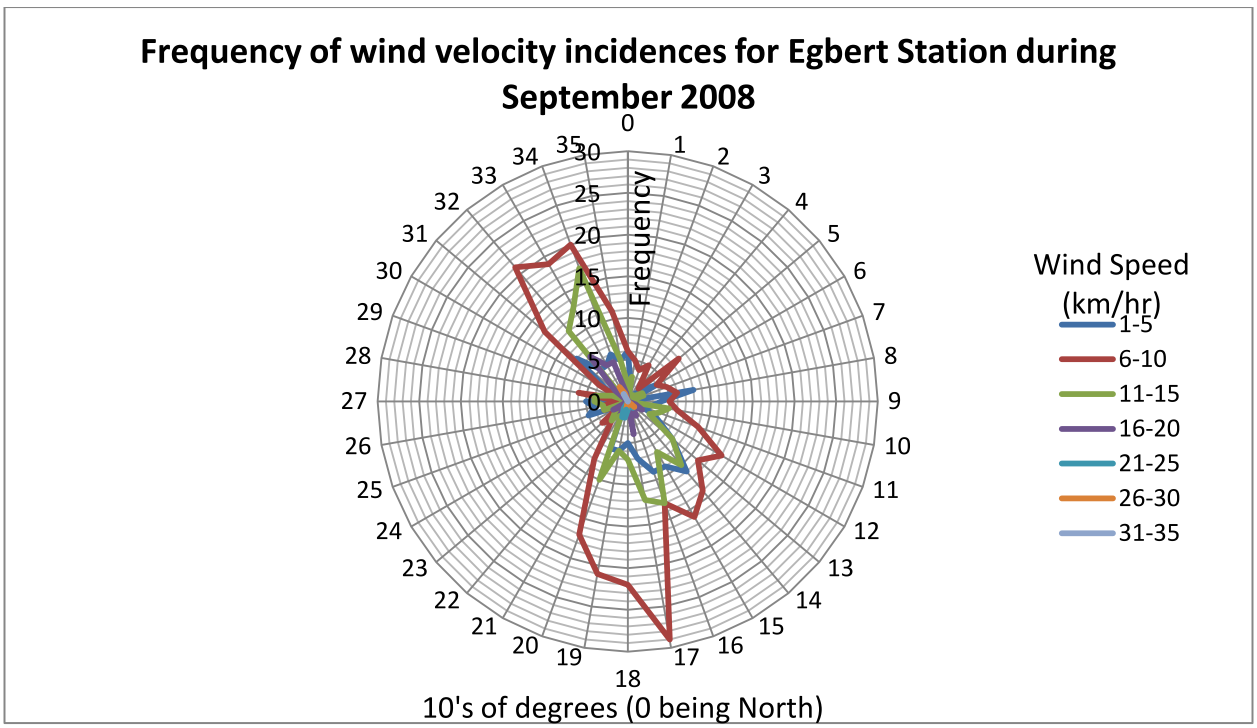

Figure 10.9: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during September 2008.

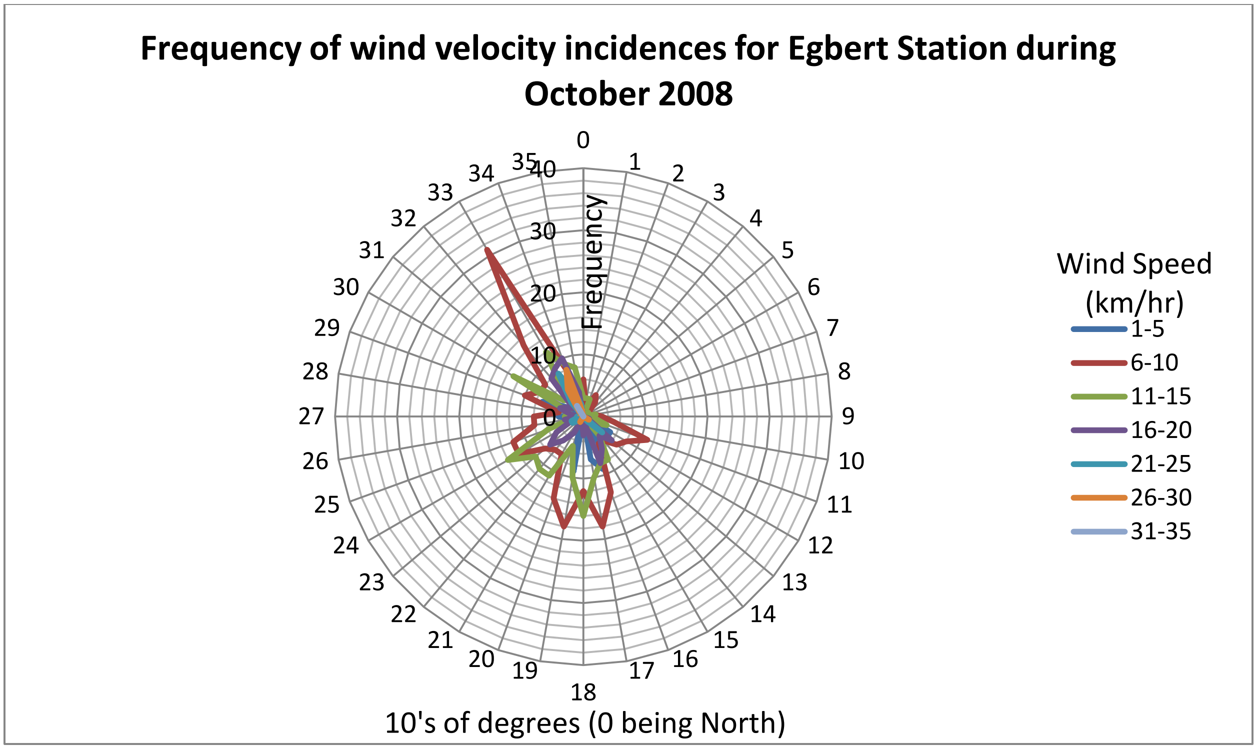

Figure 10.10: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during October 2008.

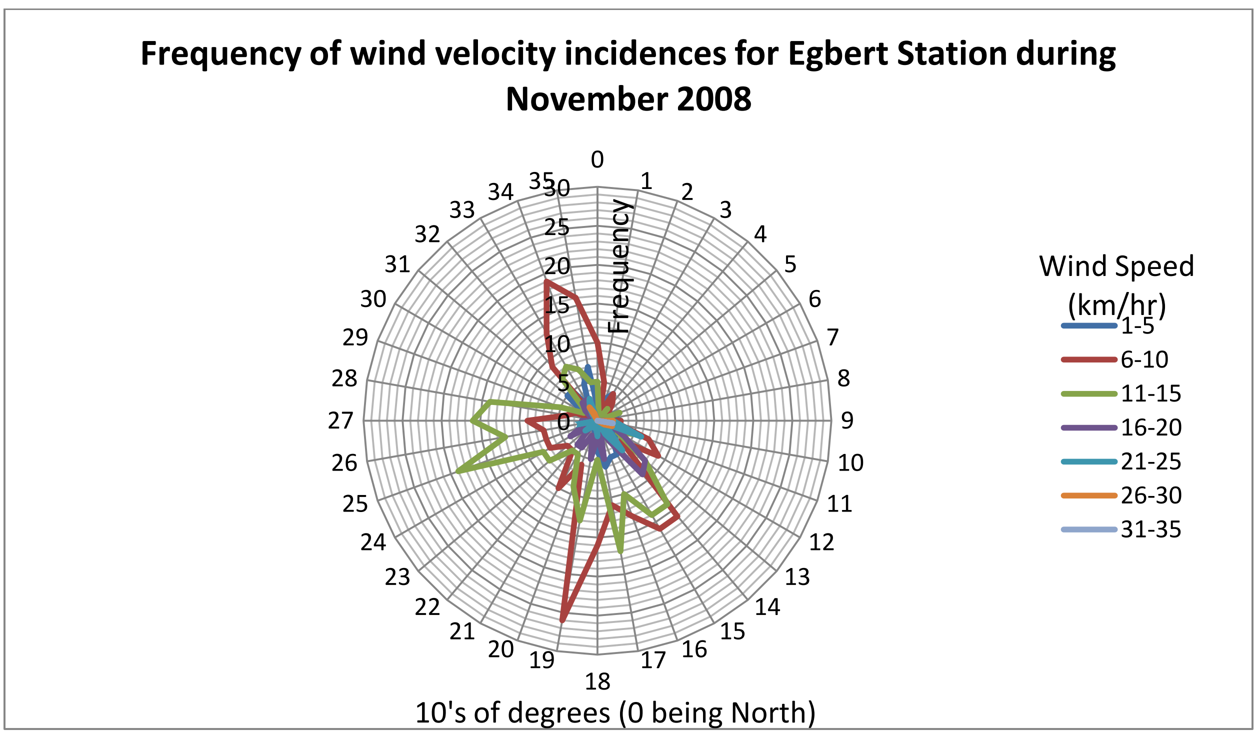

Figure 10.11: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during November 2008.

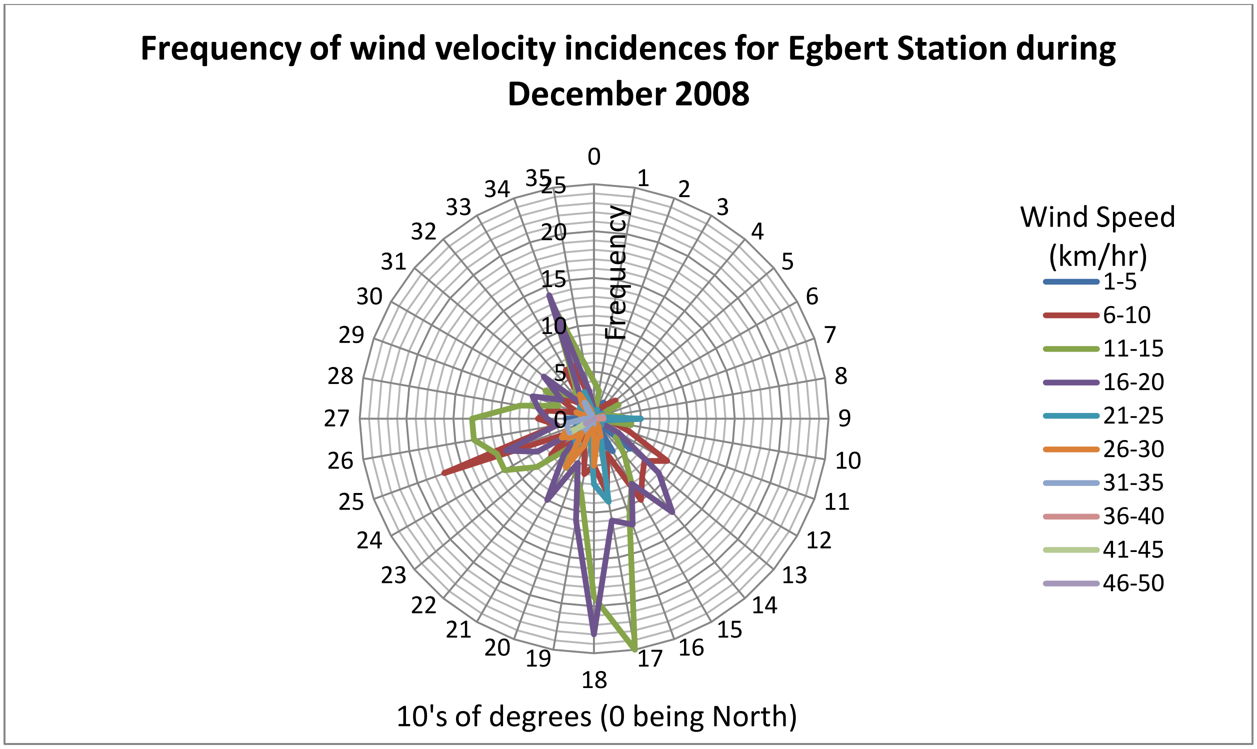

Figure 10.12: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during December 2008.

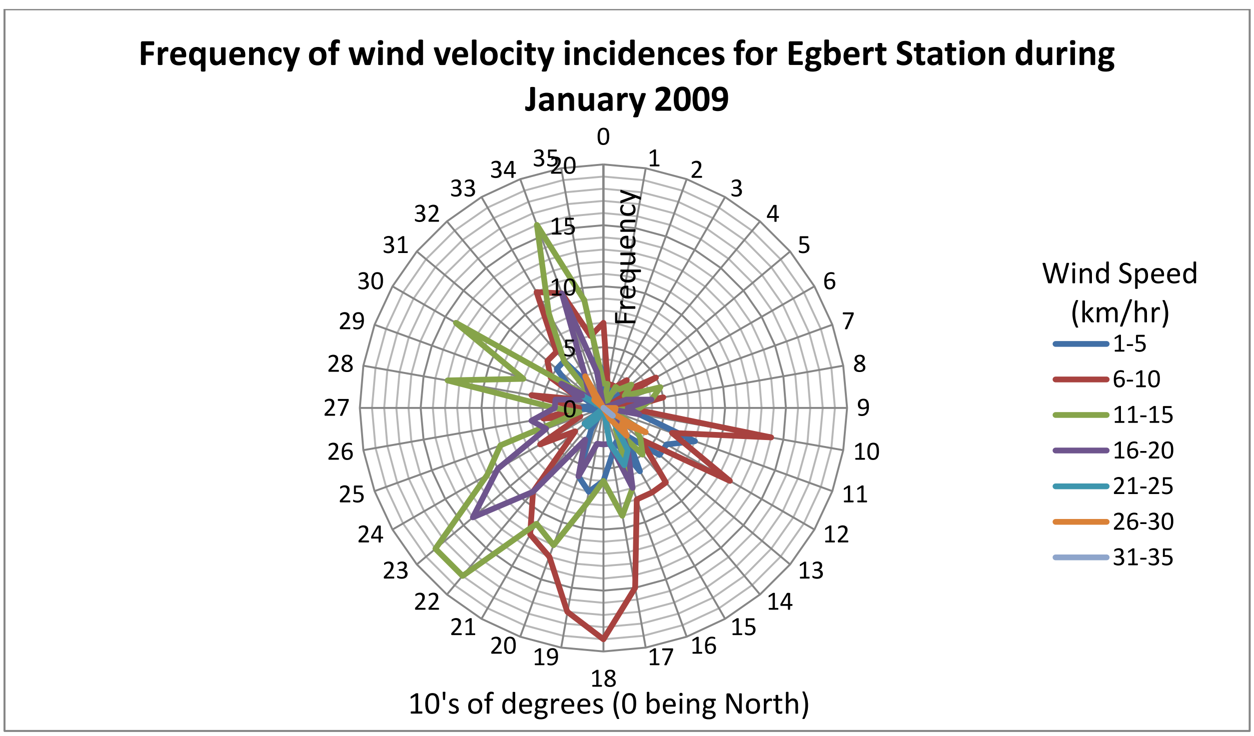

Figure 10.13: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during January 2009.

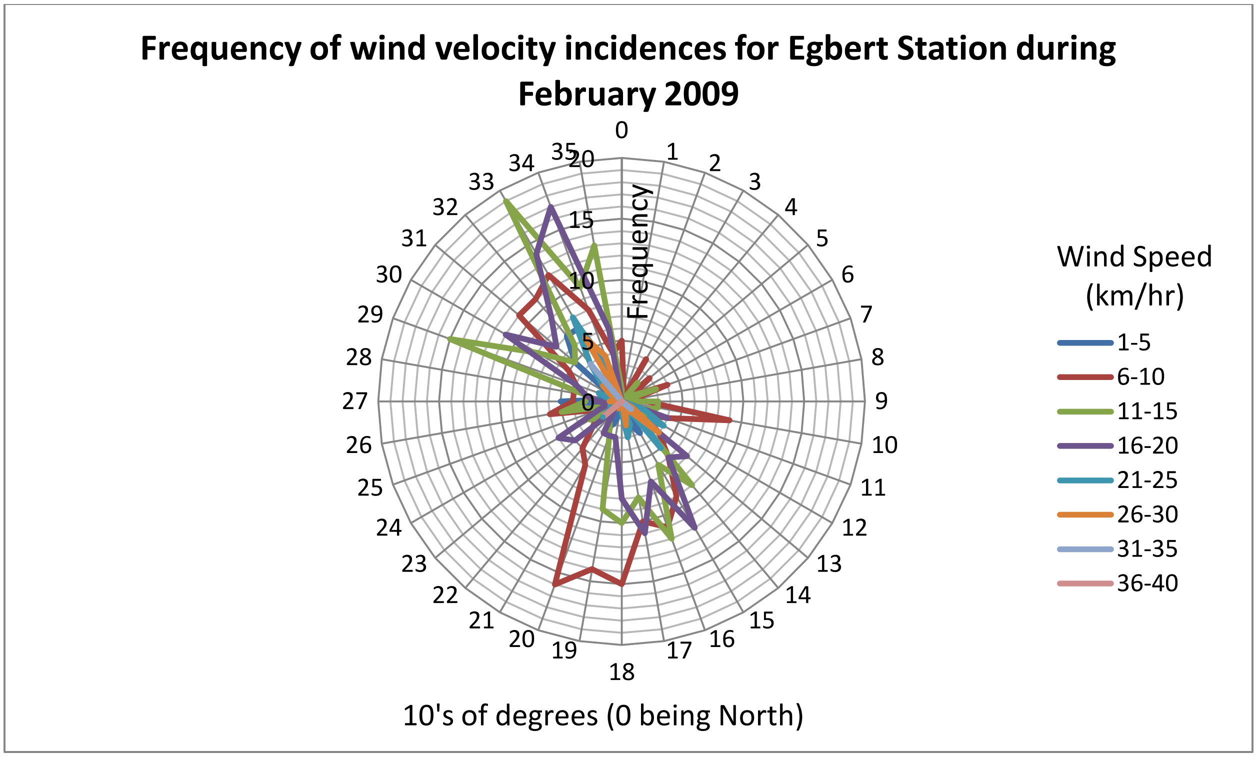

Figure 10.14: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during February 2009.

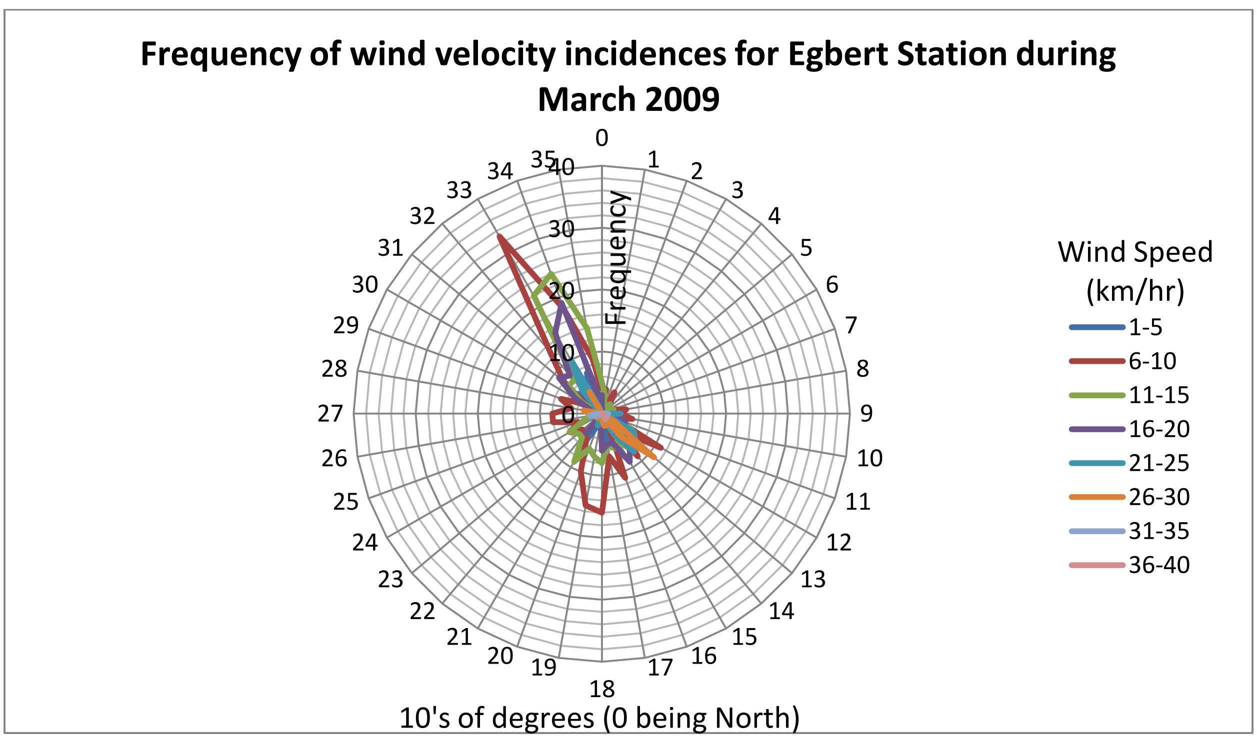

Figure 10.15: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during March 2009.

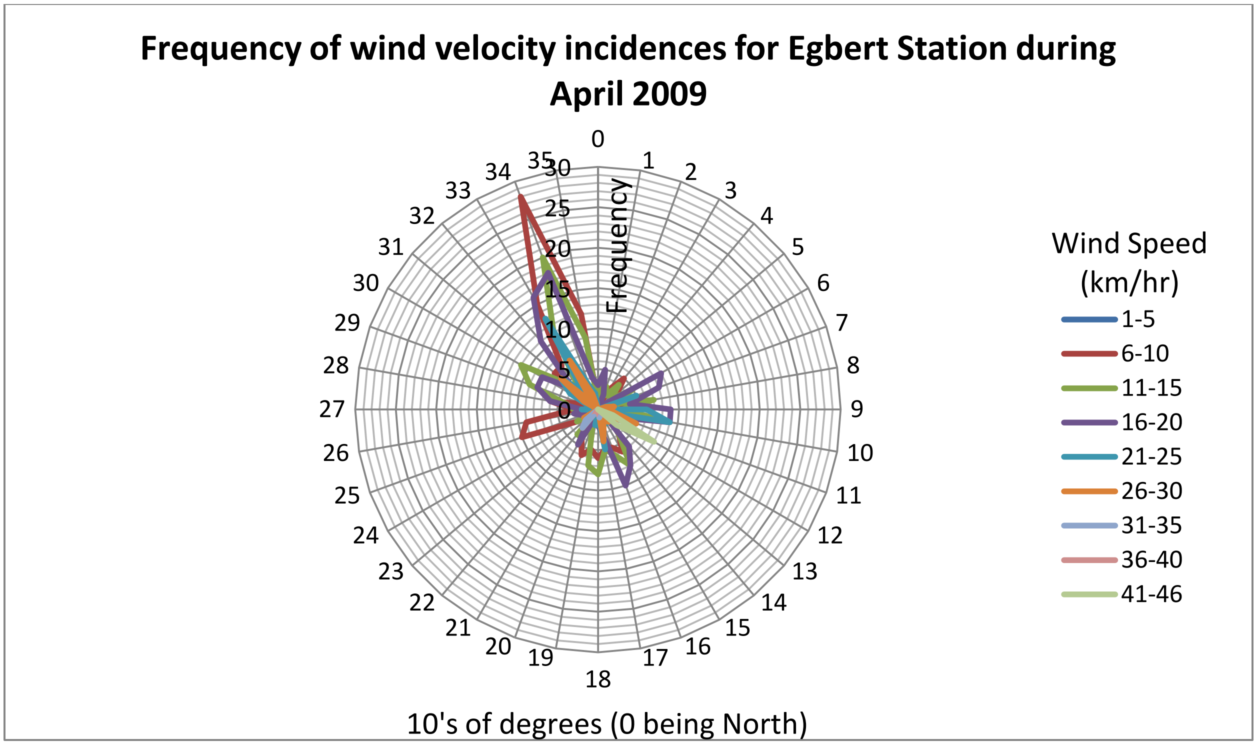

Figure 10.16: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during April 2009.

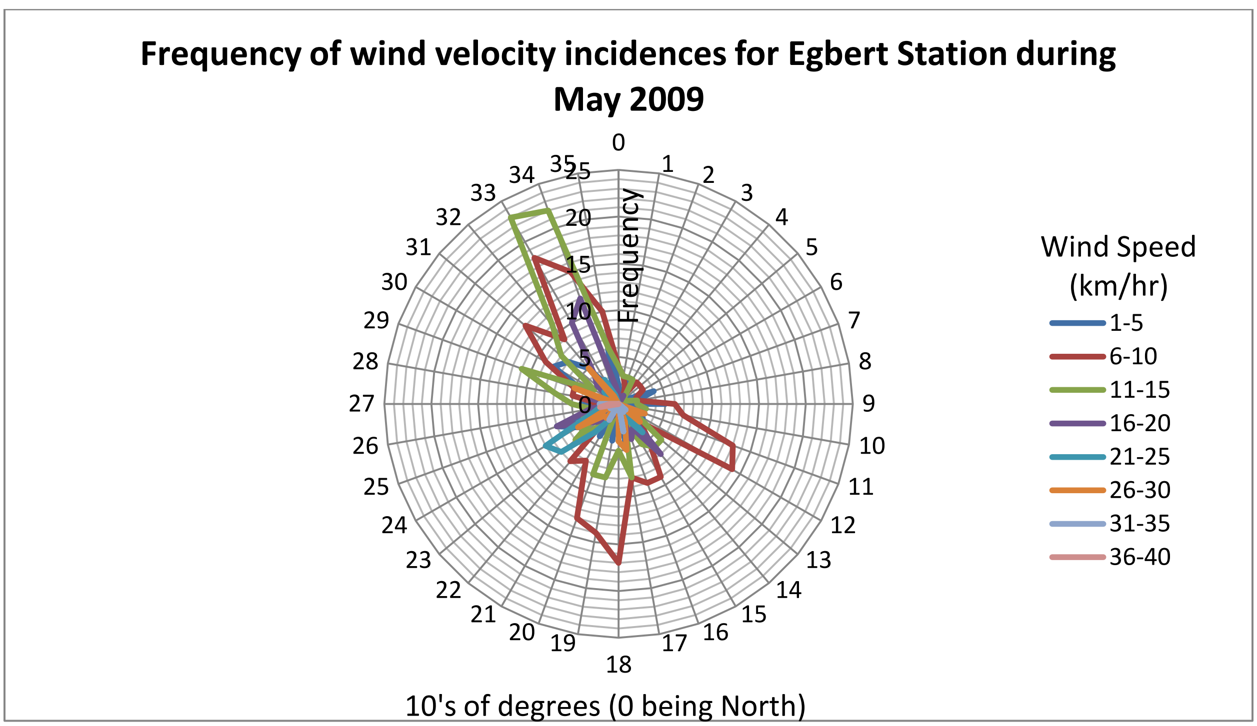

Figure 10.17: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during May 2009.

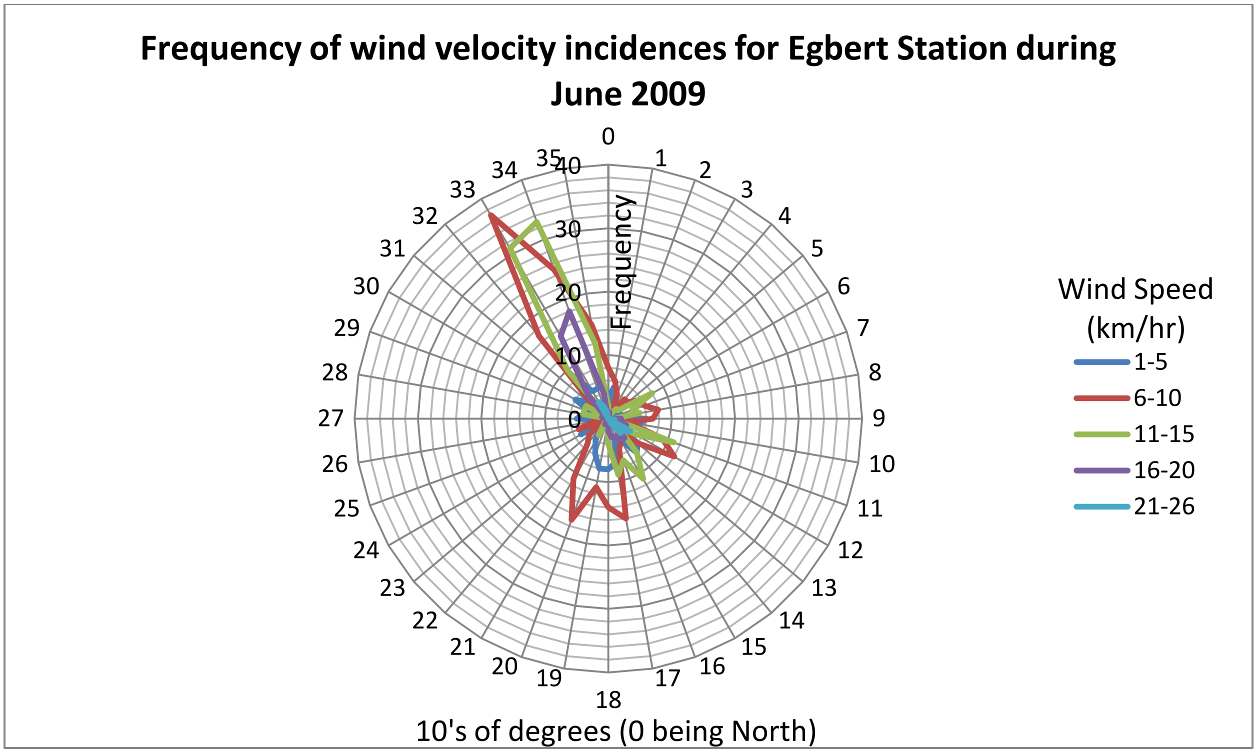

Figure 10.18: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during June 2009.

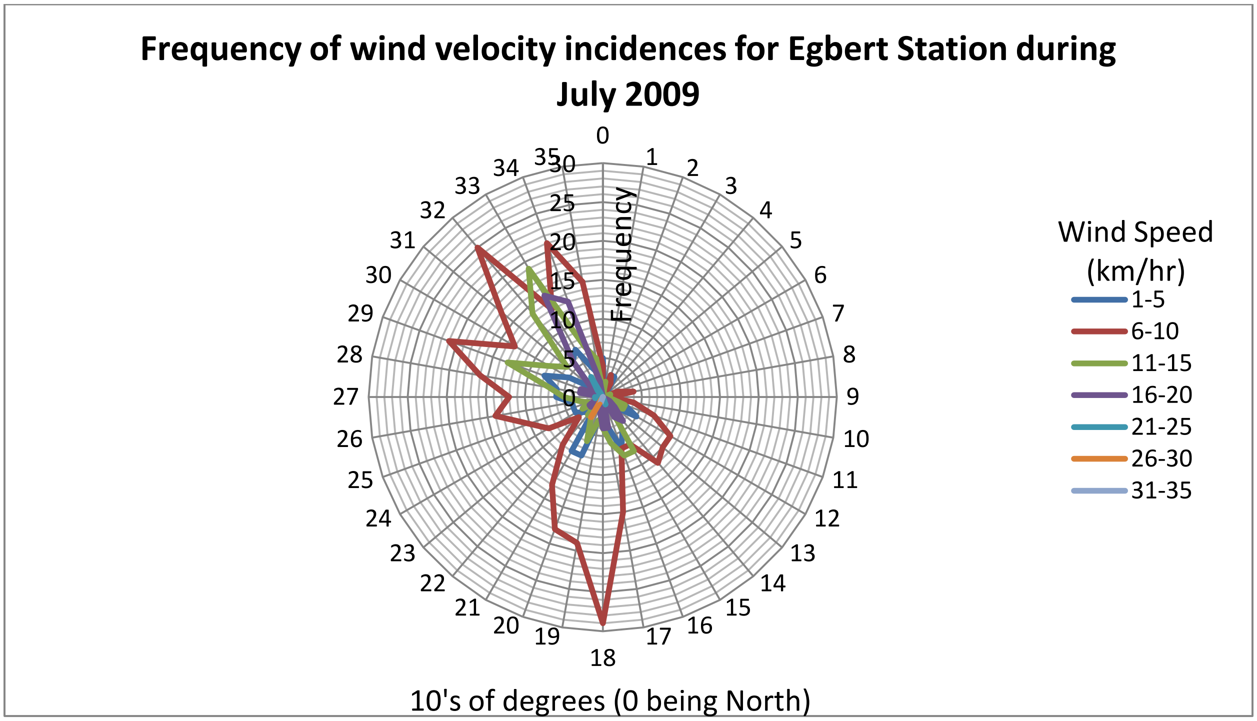

Figure 10.19: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during July 2009.

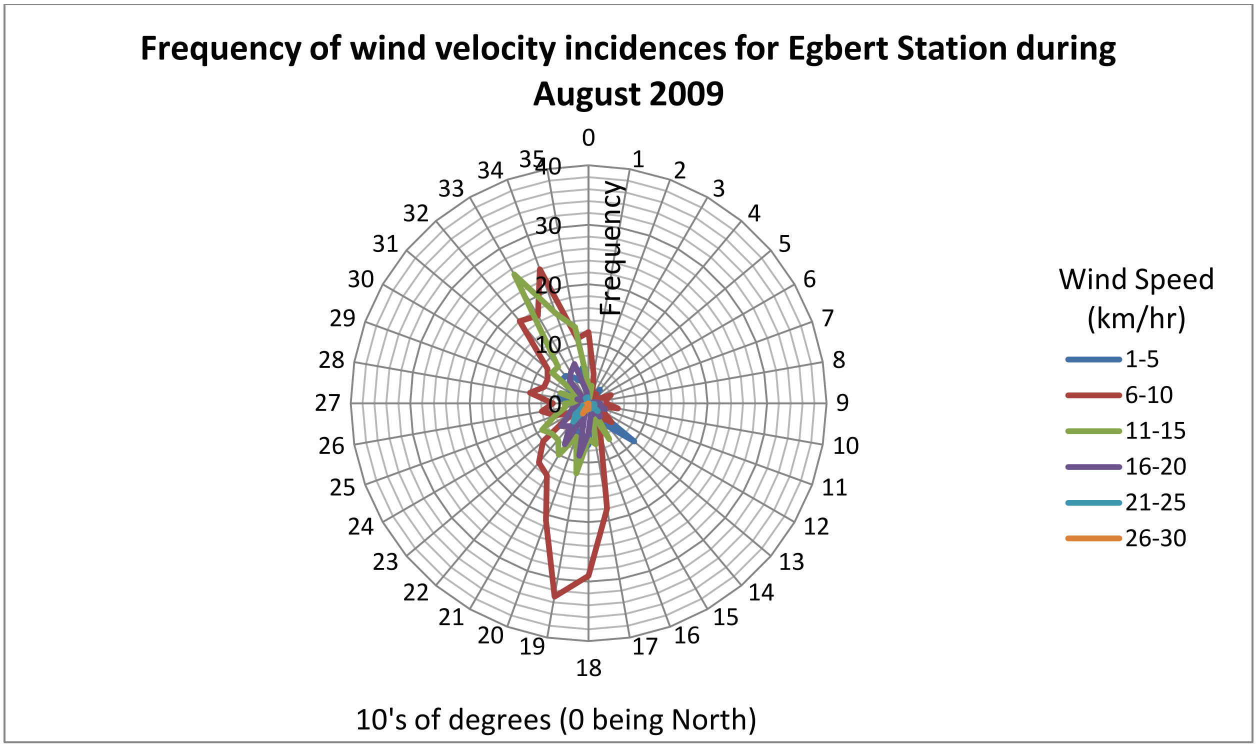

Figure 10.20: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during August 2009.

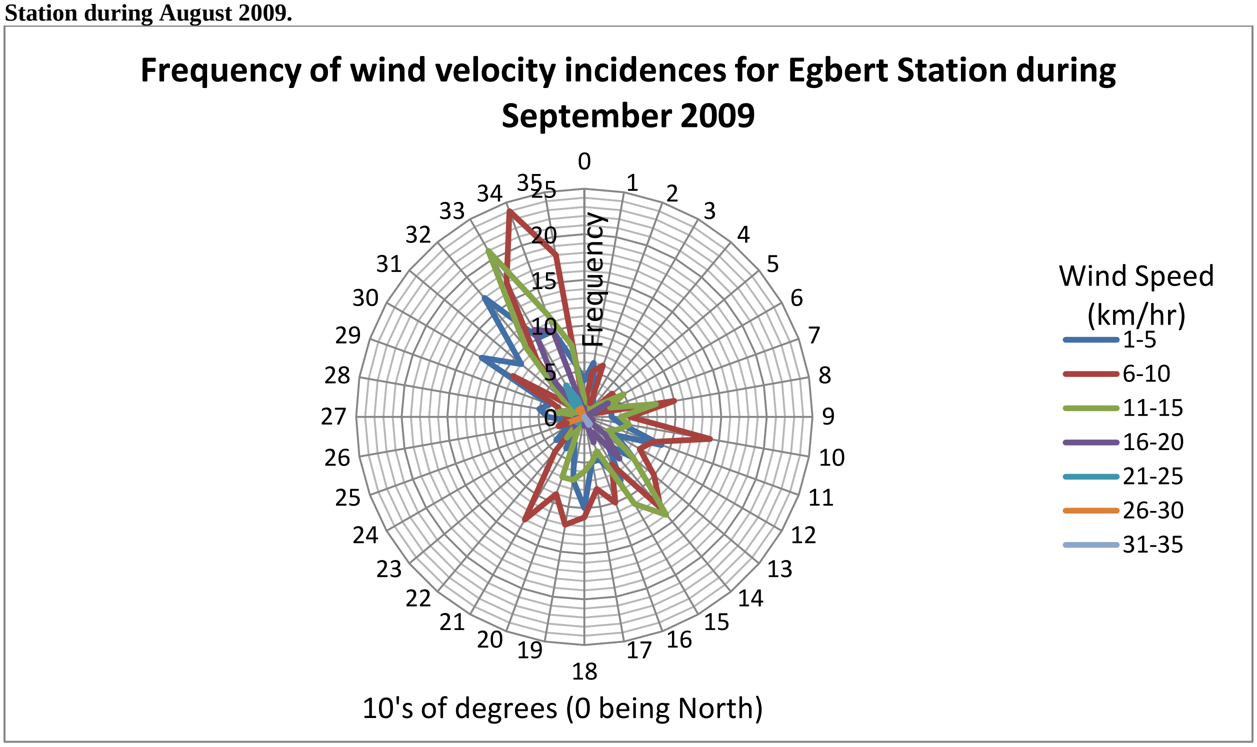

Figure 10.21: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during September 2009.

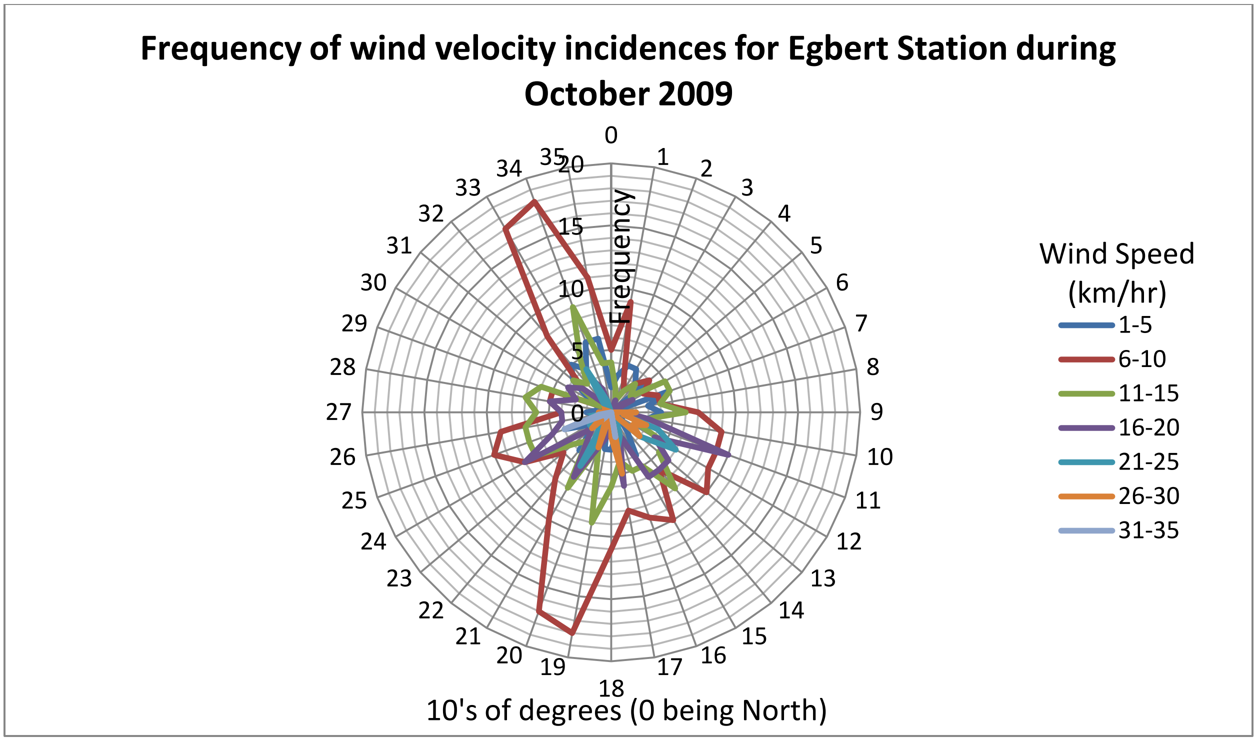

Figure 10.22: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during October 2009.

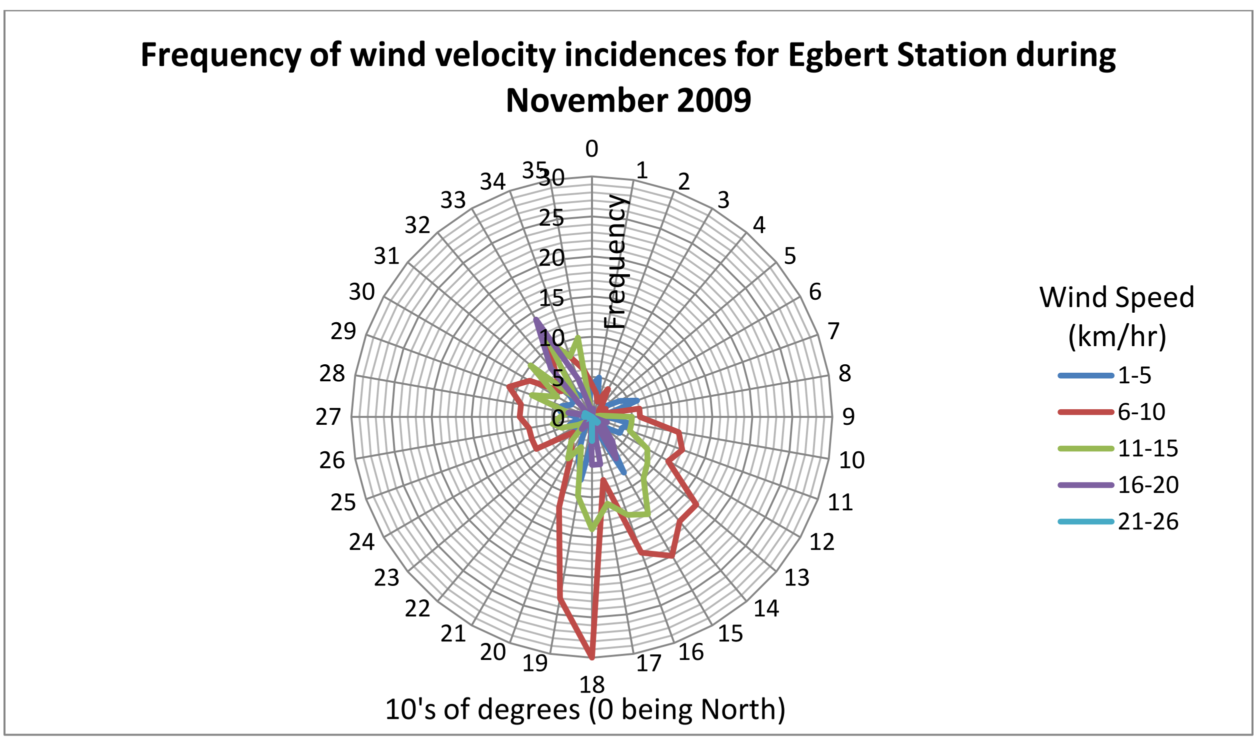

Figure 10.23: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during November 2009.

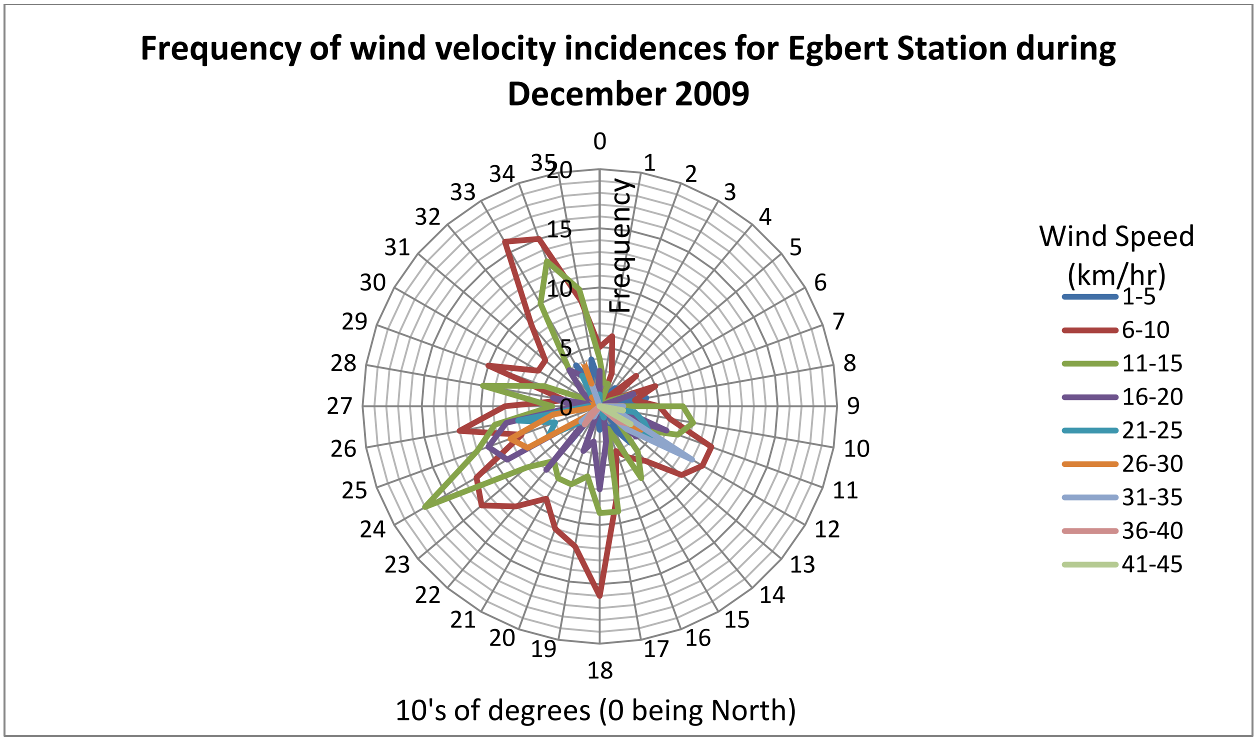

Figure 10.24: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during December 2009.

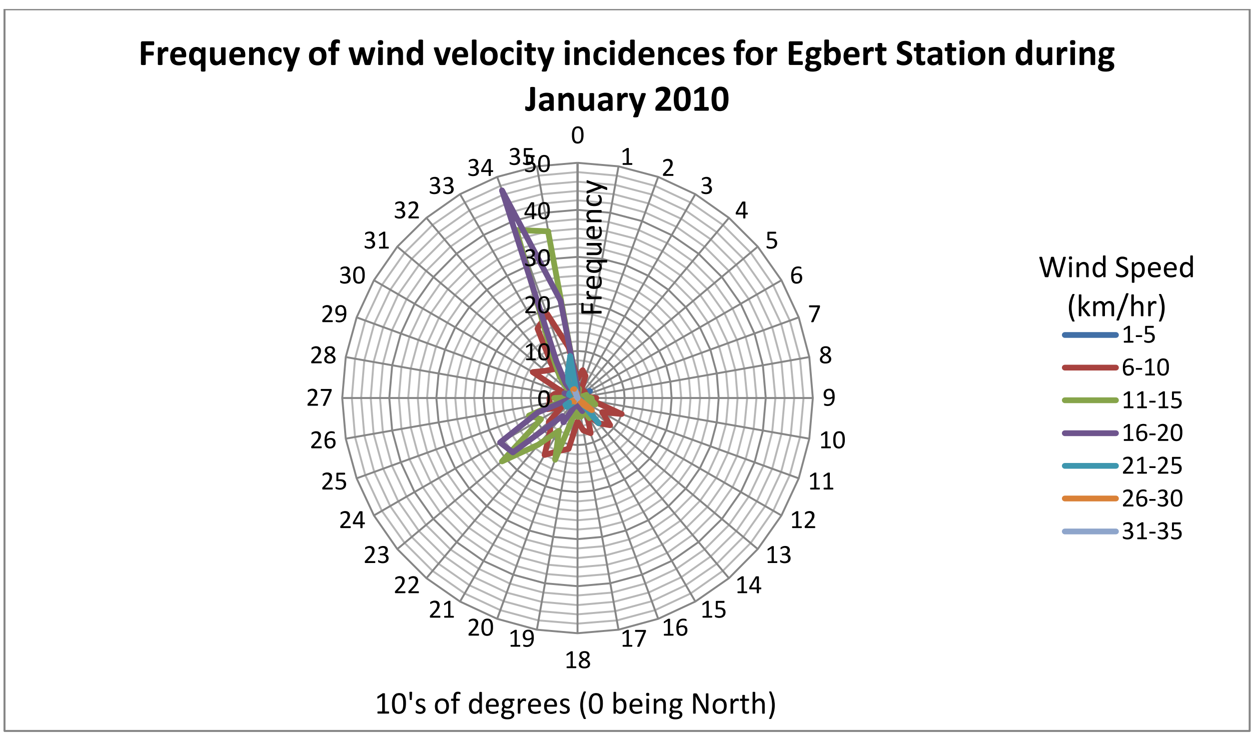

Figure 10.25: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during January 2010.

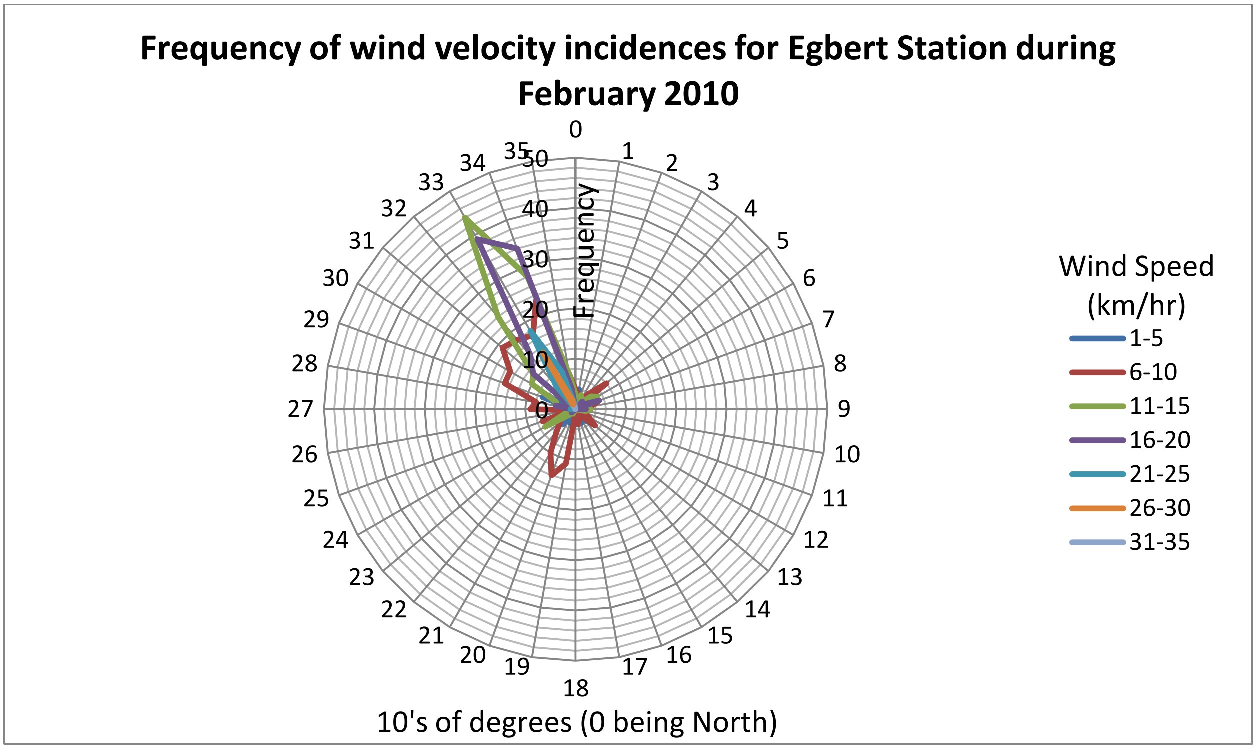

Figure 10.26: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during February 2010.

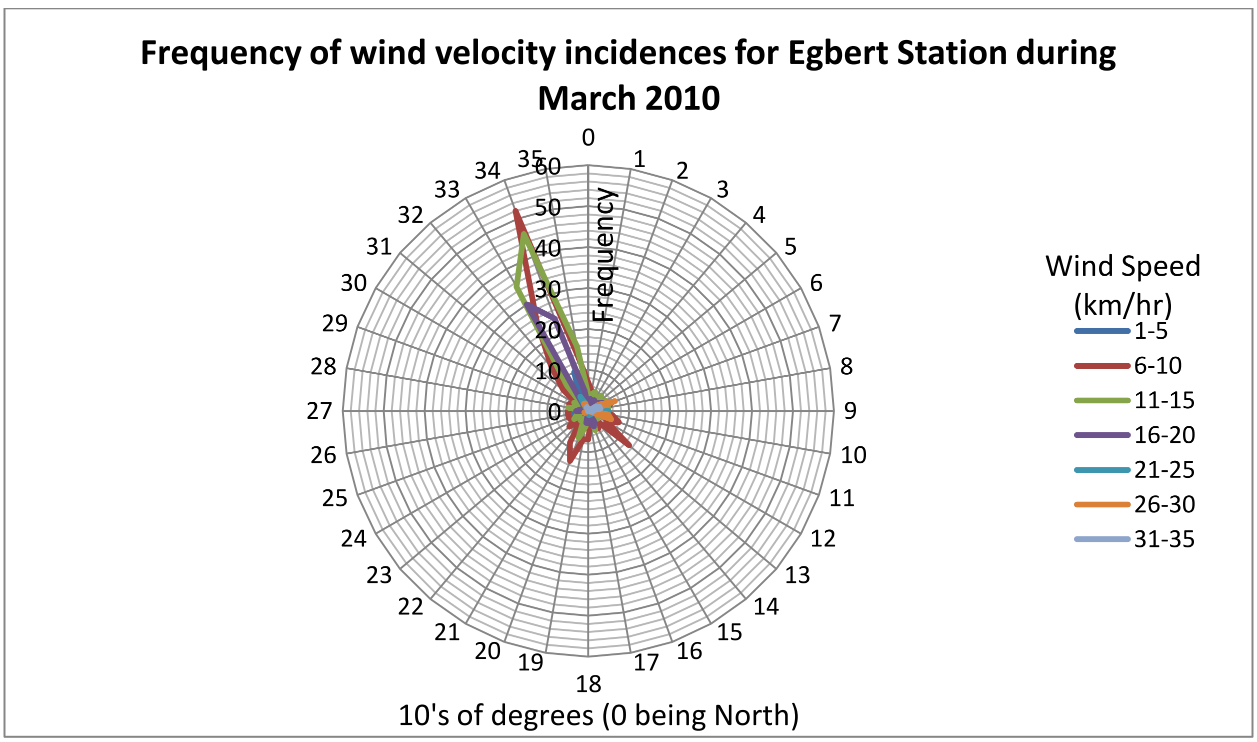

Figure 10.27: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during March 2010.

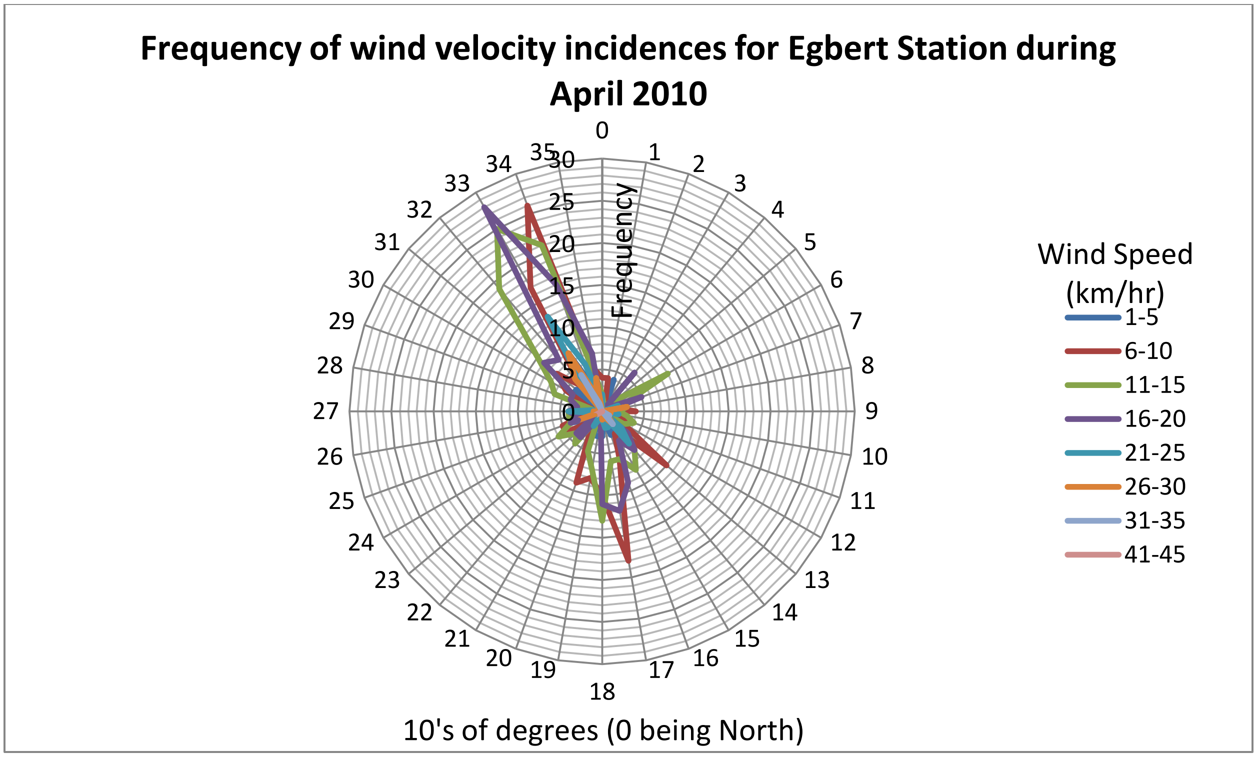

Figure 10.28: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during April 2010.

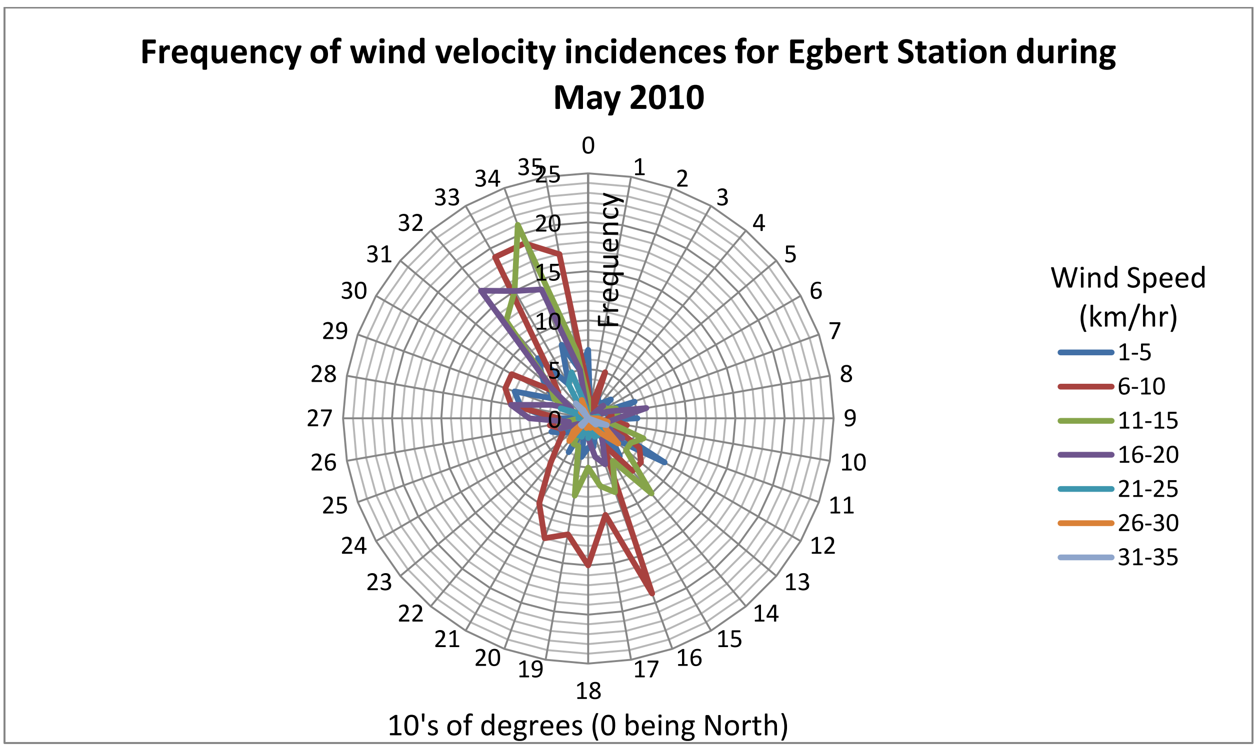

Figure 10.29: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during May 2010.

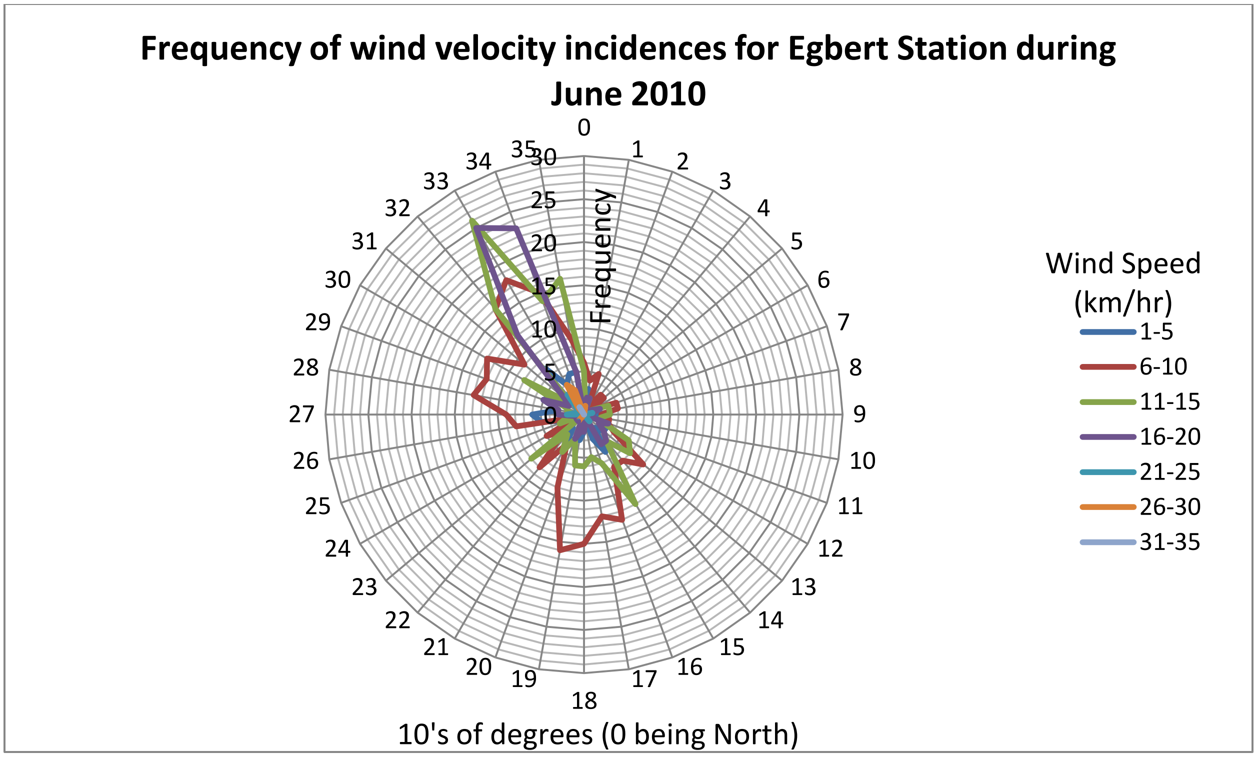

Figure 10.30: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during June 2010.

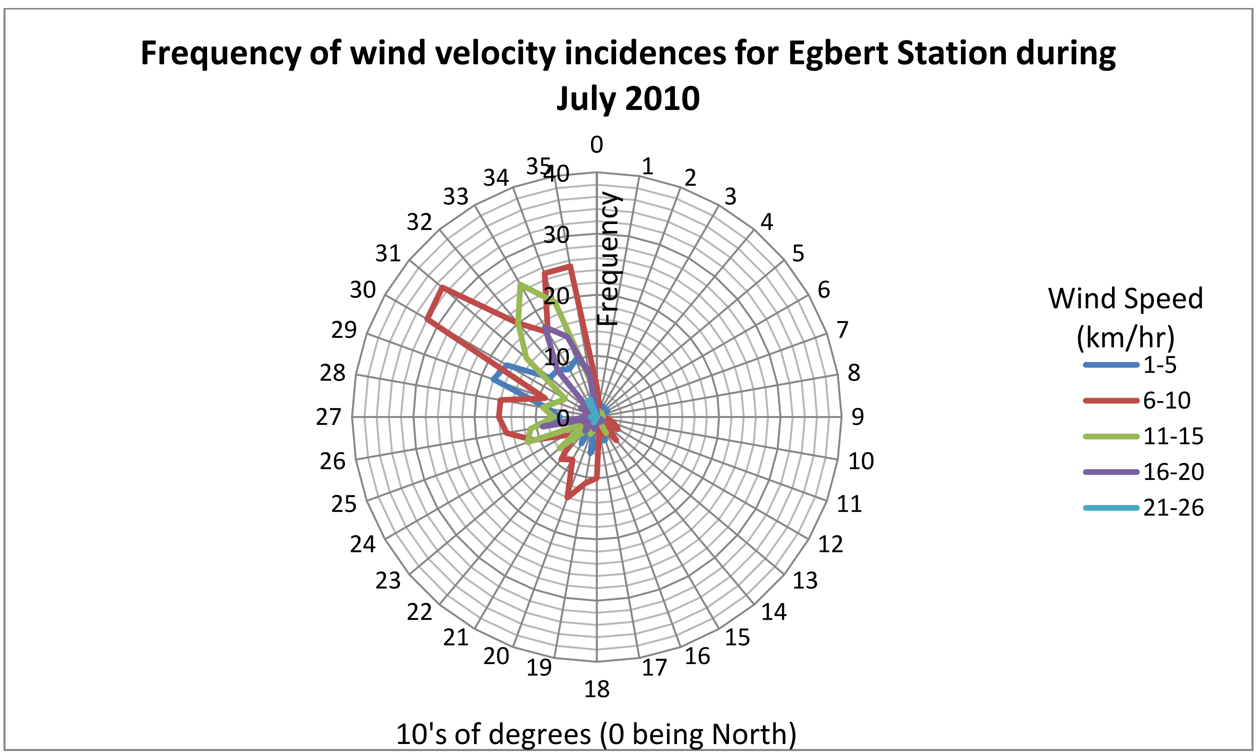

Figure 10.31: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during July 2010.

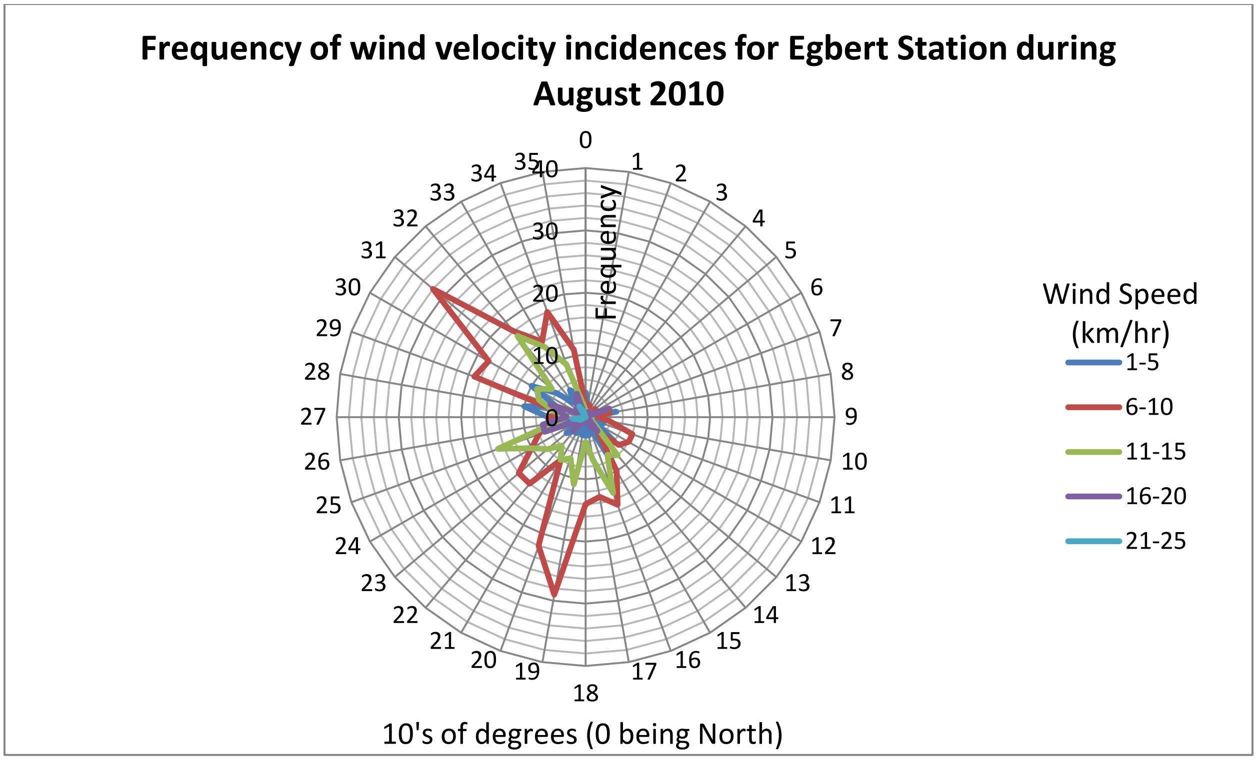

Figure 10.32: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during August 2010.

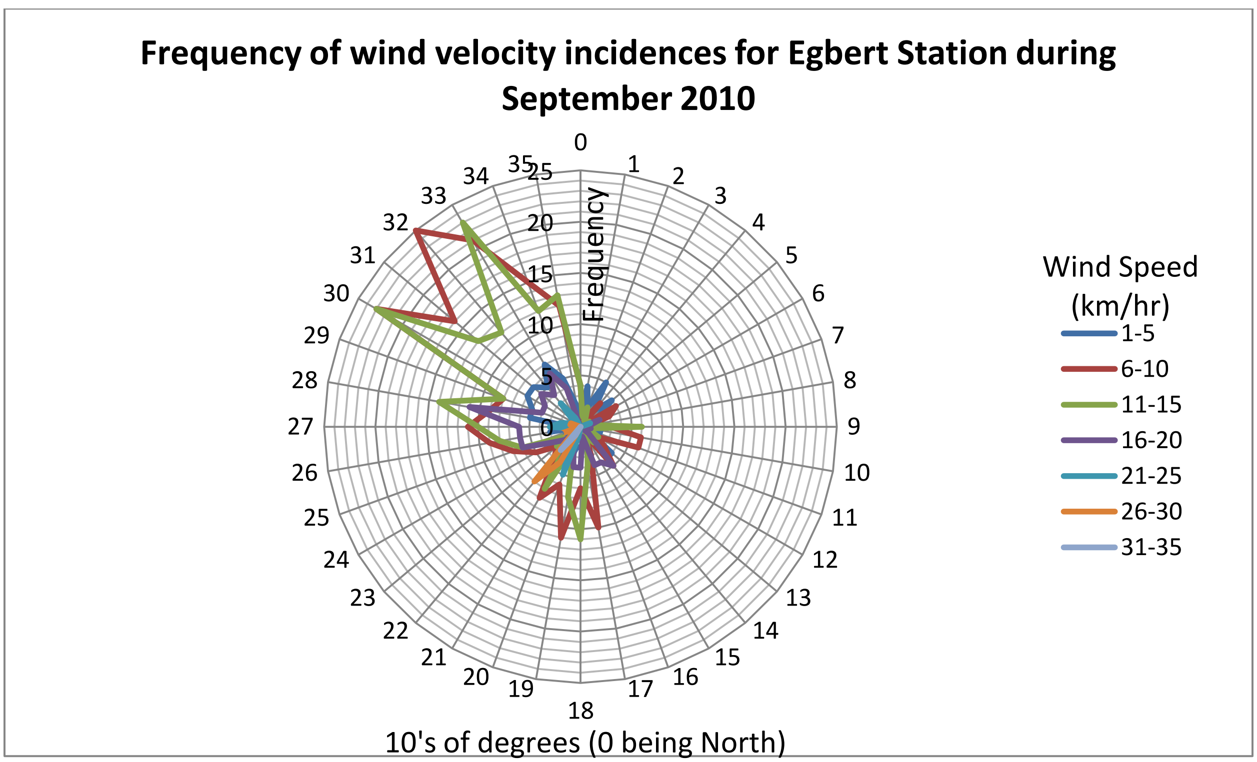

Figure 10.33: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during September 2010.

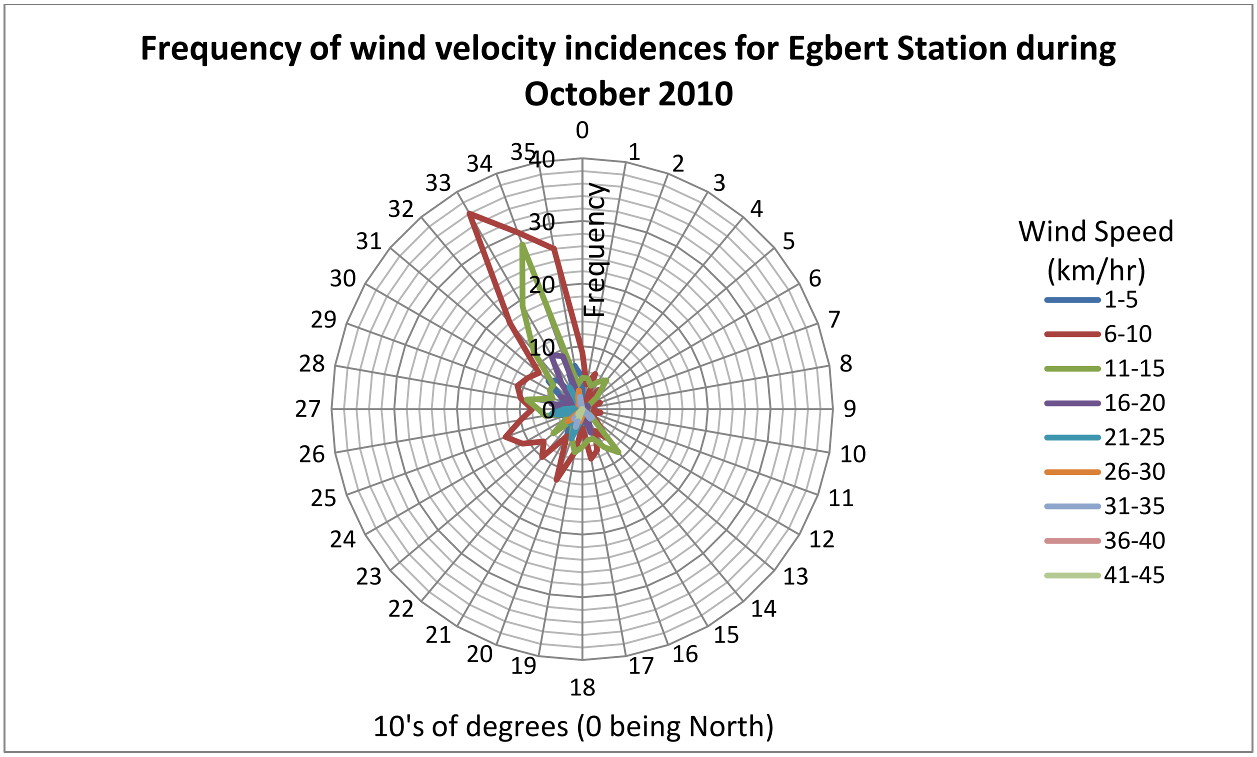

Figure 10.34: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during October 2010.

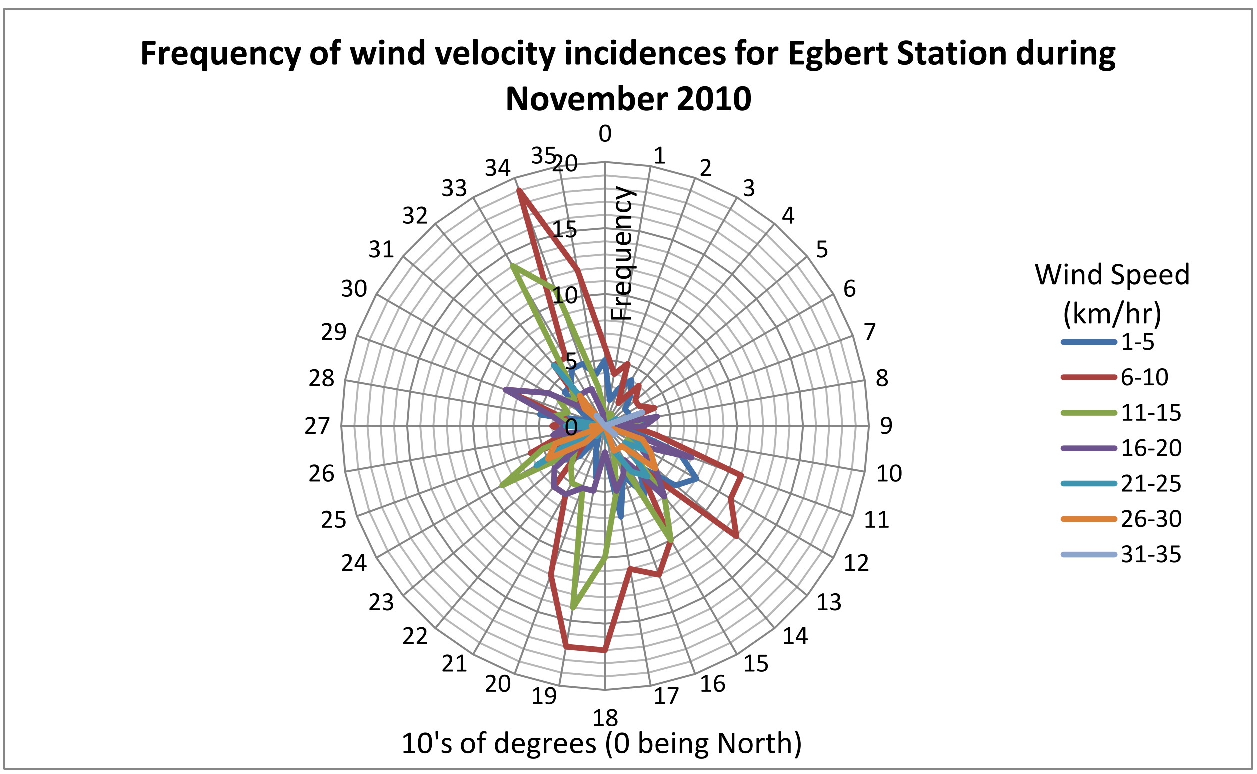

Figure 10.35: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during November 2010.

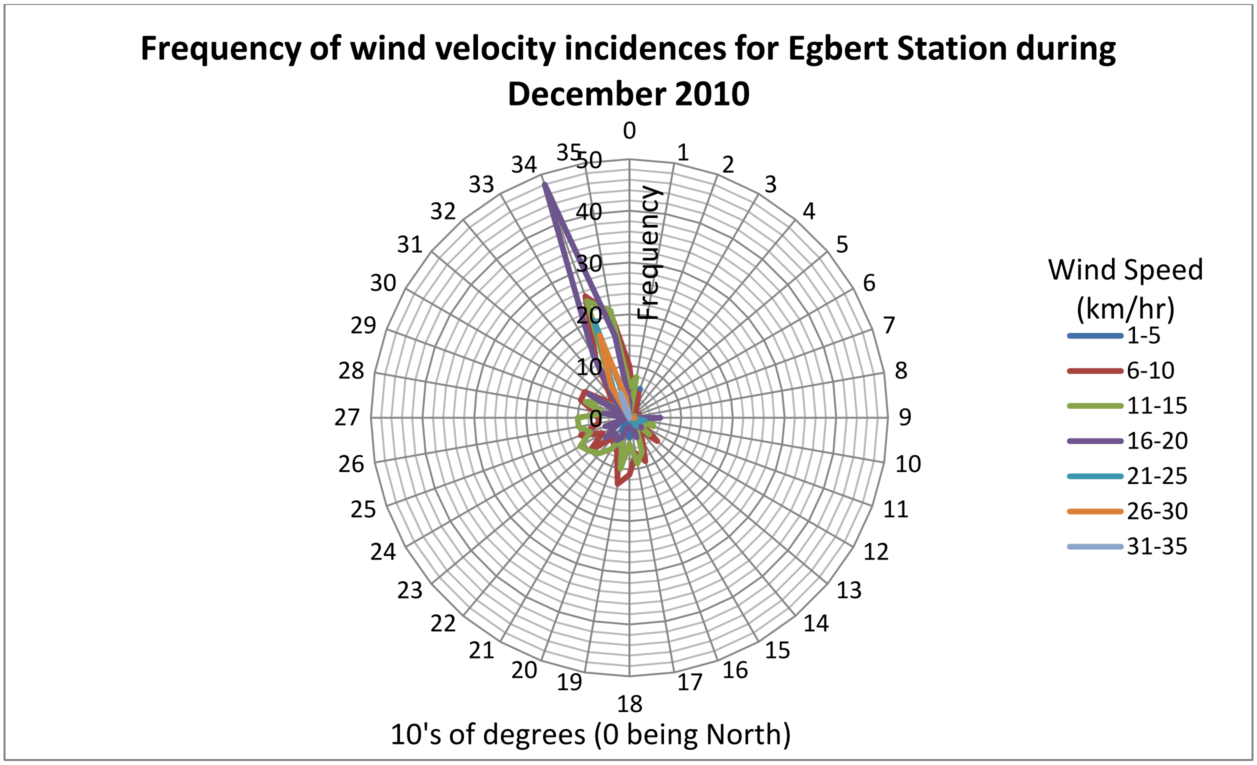

Figure 10.36: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during December 2010.

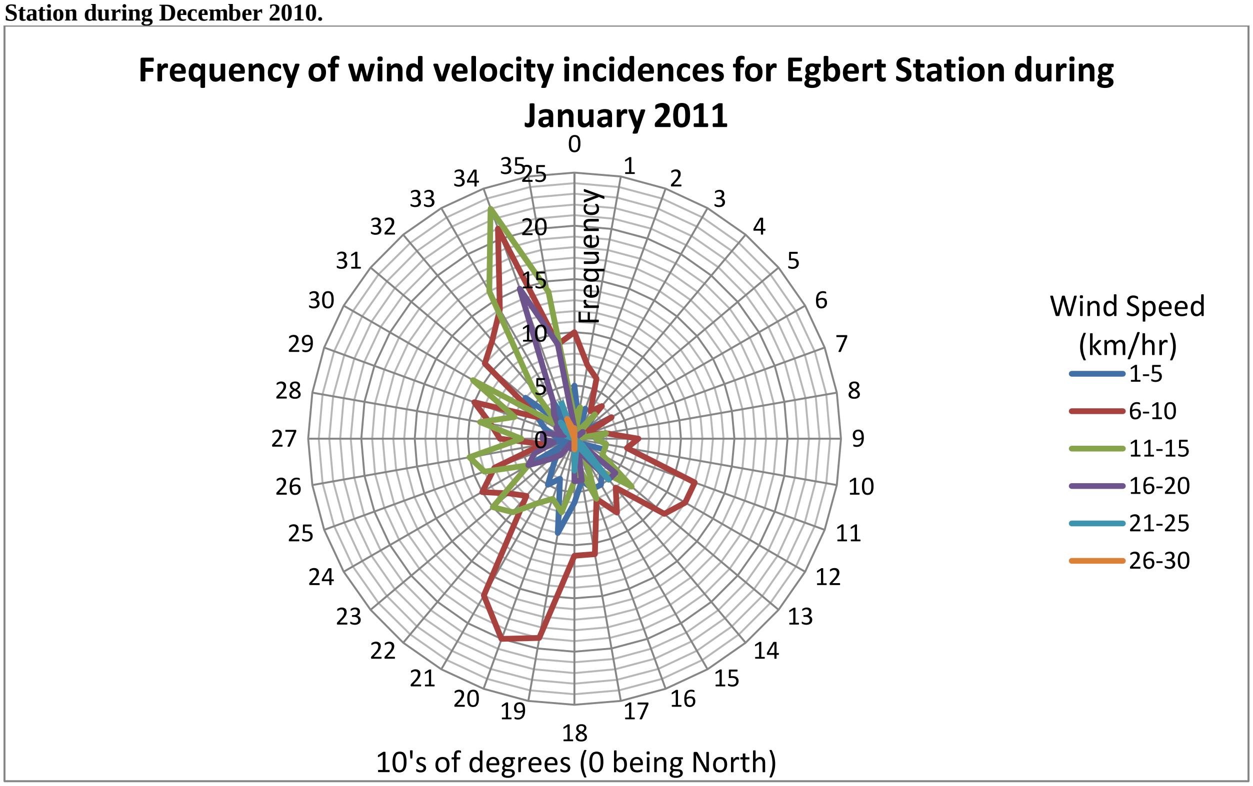

Figure 10.37: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during January 2011.

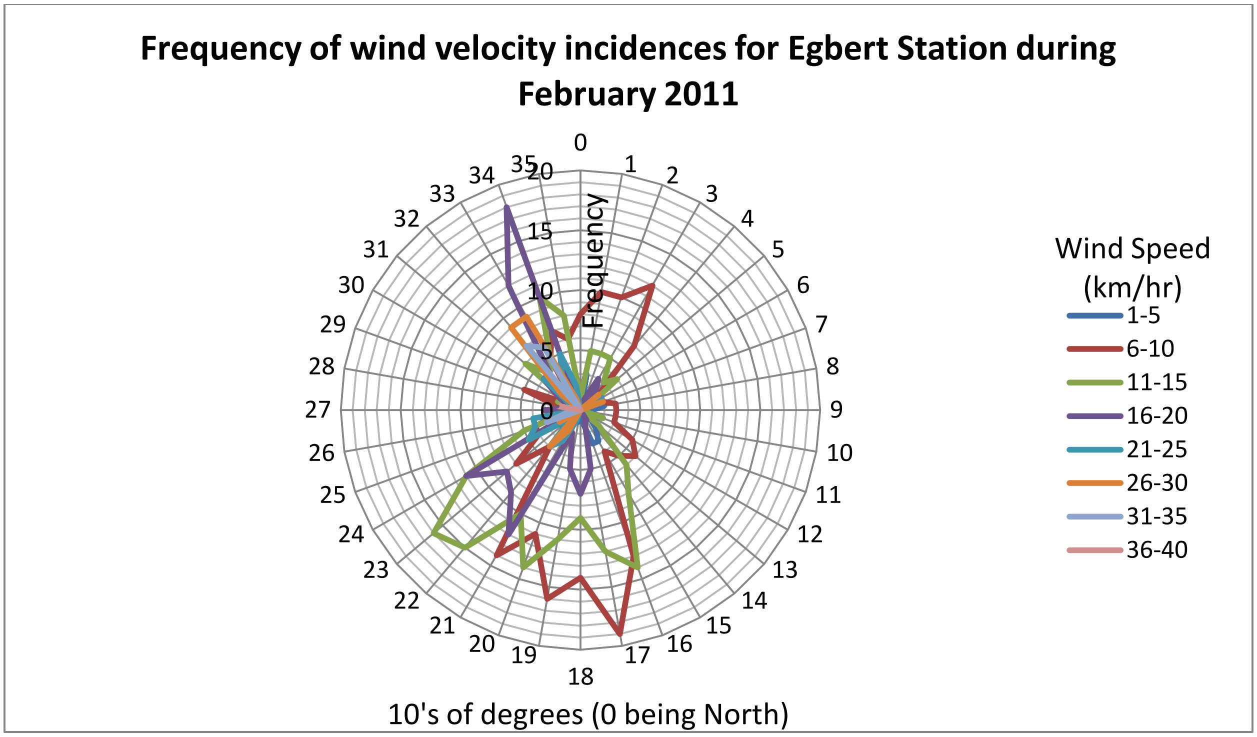

Figure 10.38: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during February 2011.

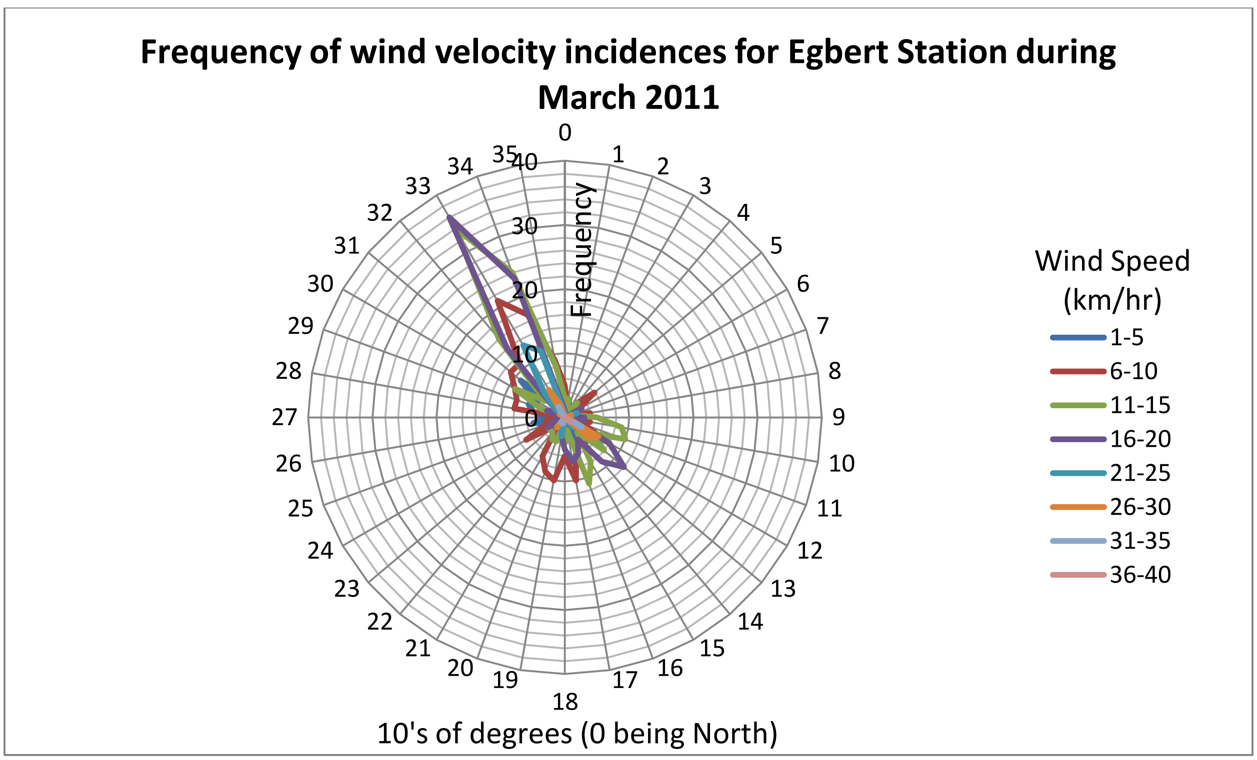

Figure 10.39: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during March 2011.

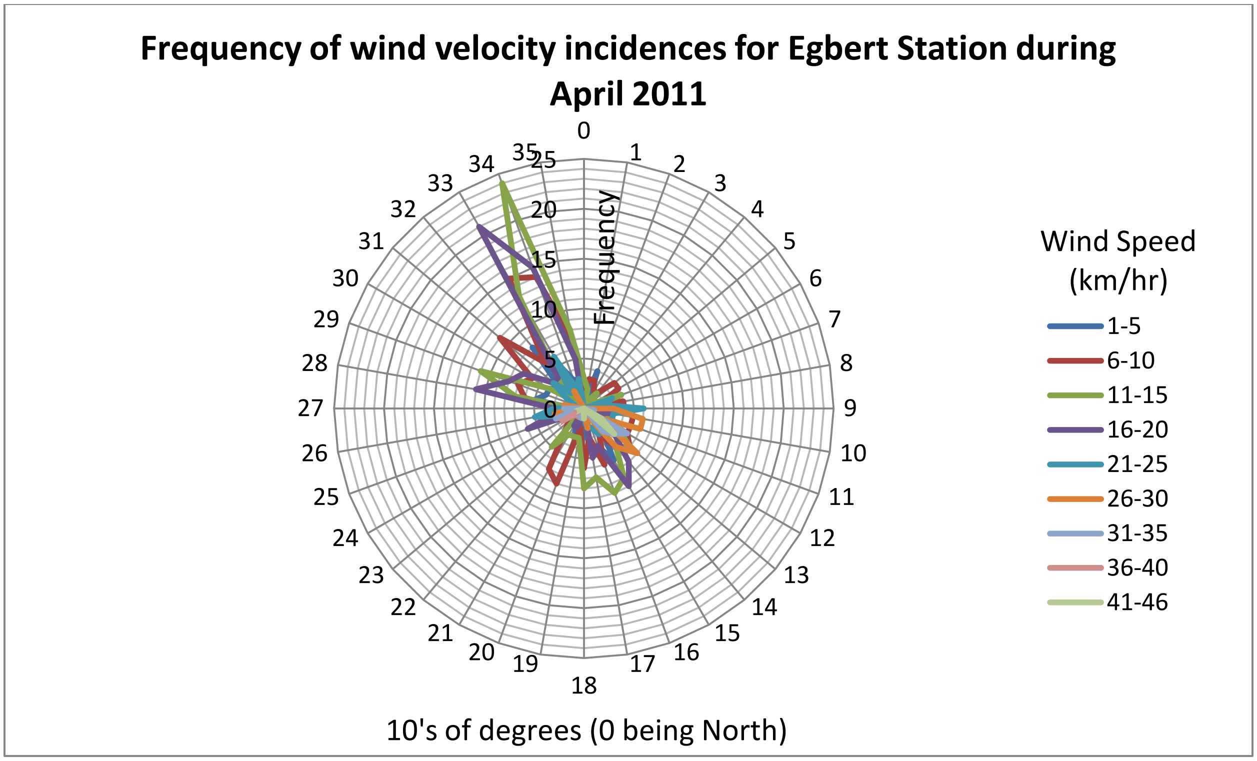

Figure 10.40: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during April 2011.

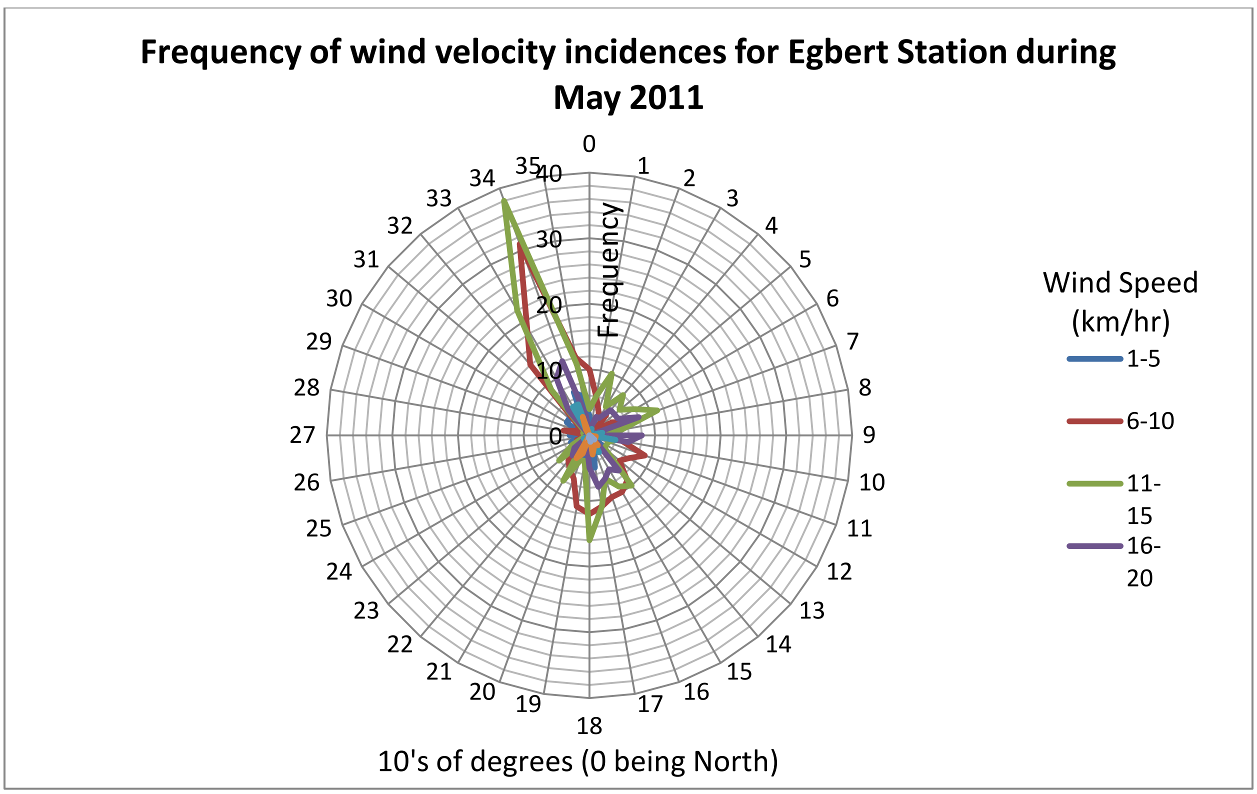

Figure 10.41: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during May 2011.

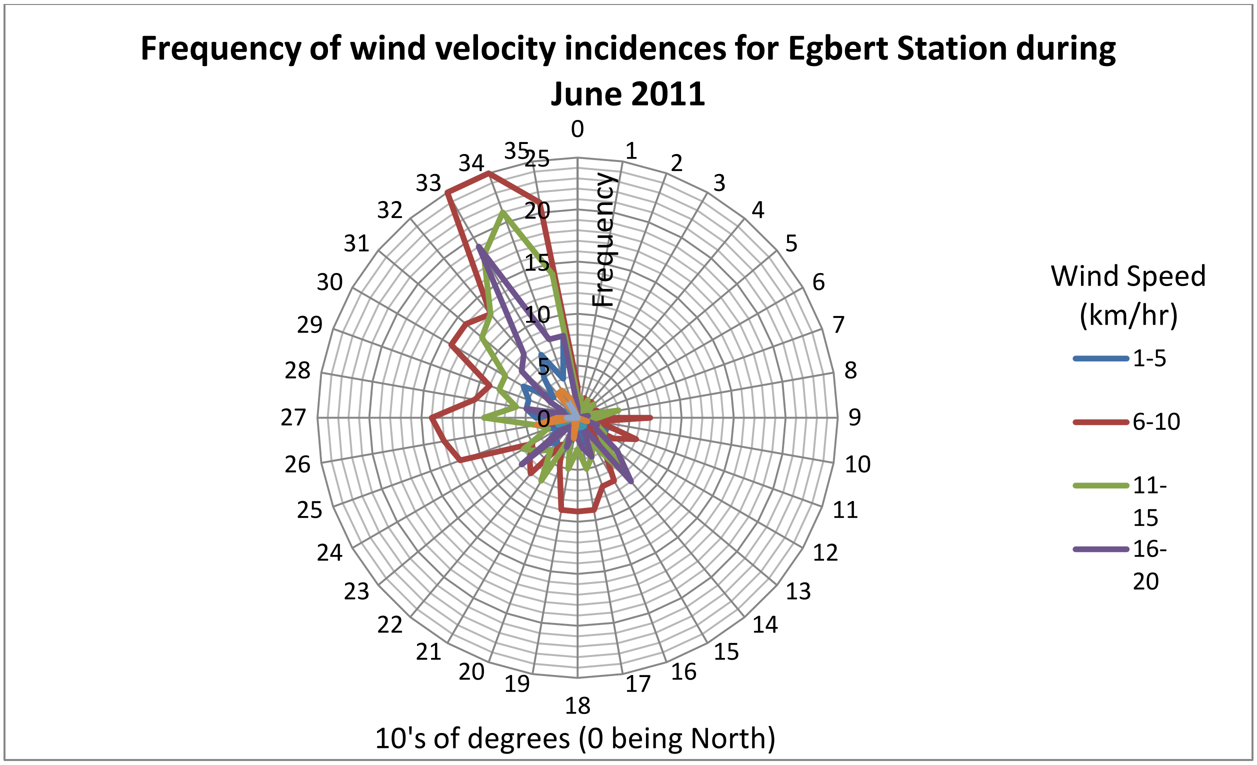

Figure 10.42: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during June 2011.

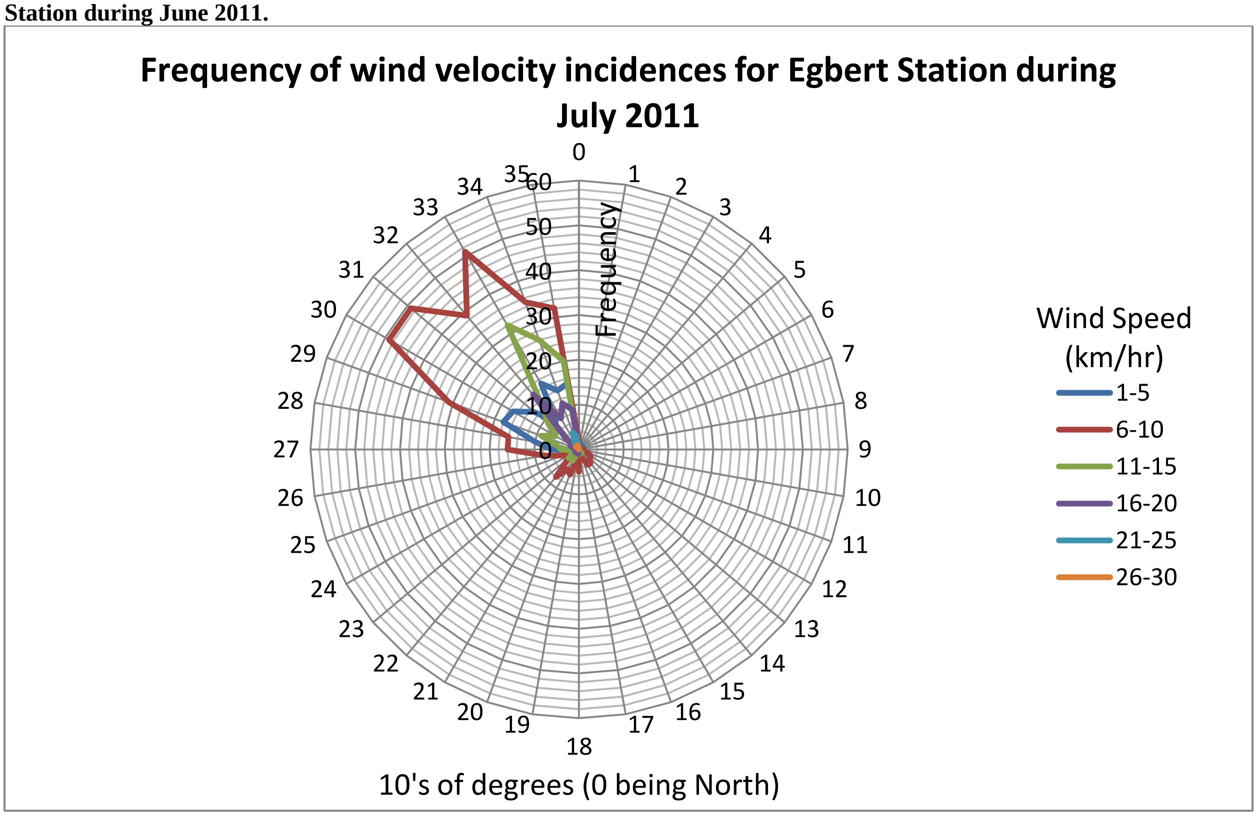

Figure 10.43: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during July 2011.

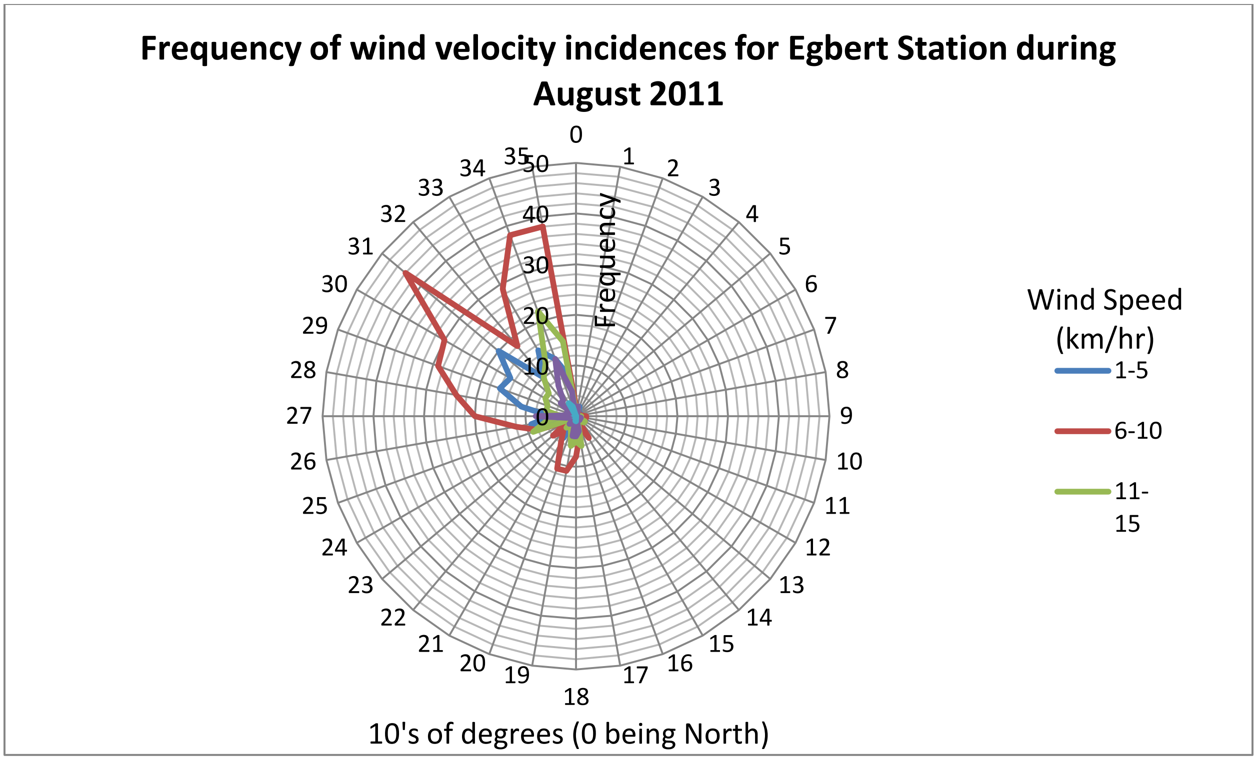

Figure 10.44: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during August 2011.

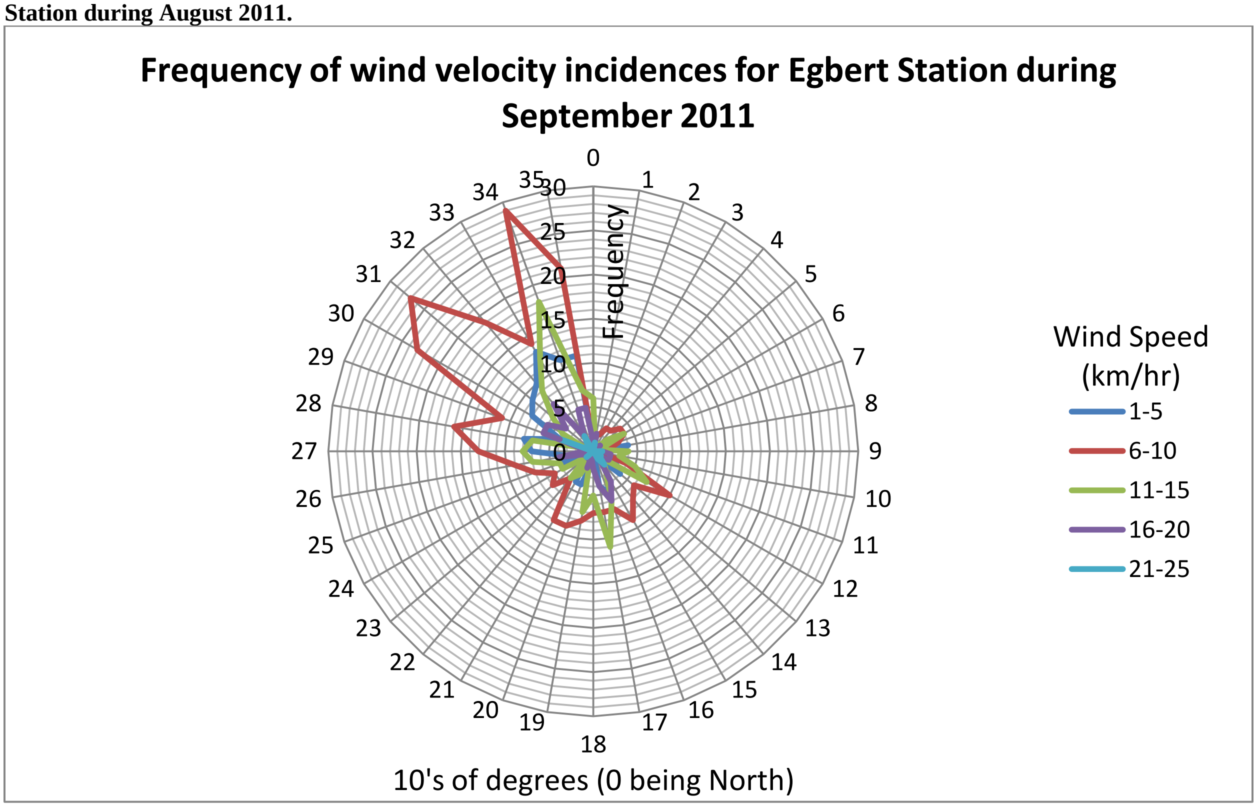

Figure 10.45: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during September 2011.

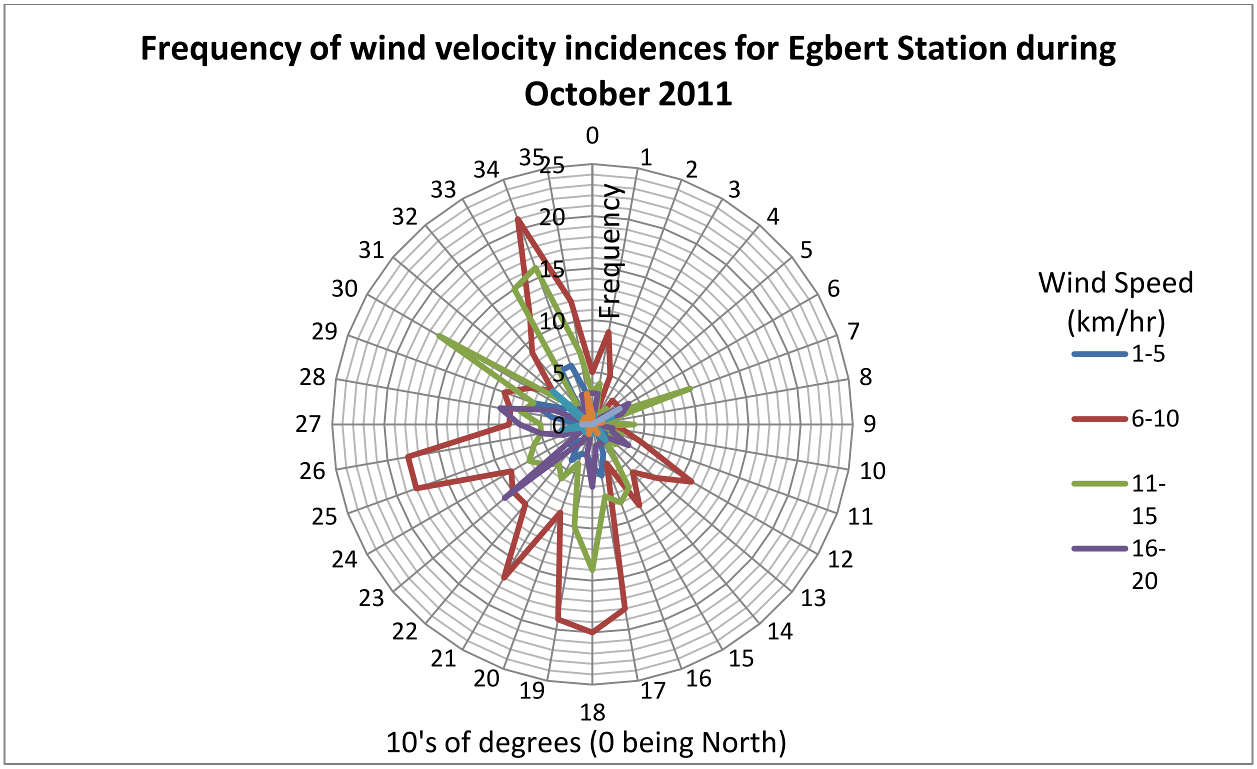

Figure 10.46: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during October 2011.

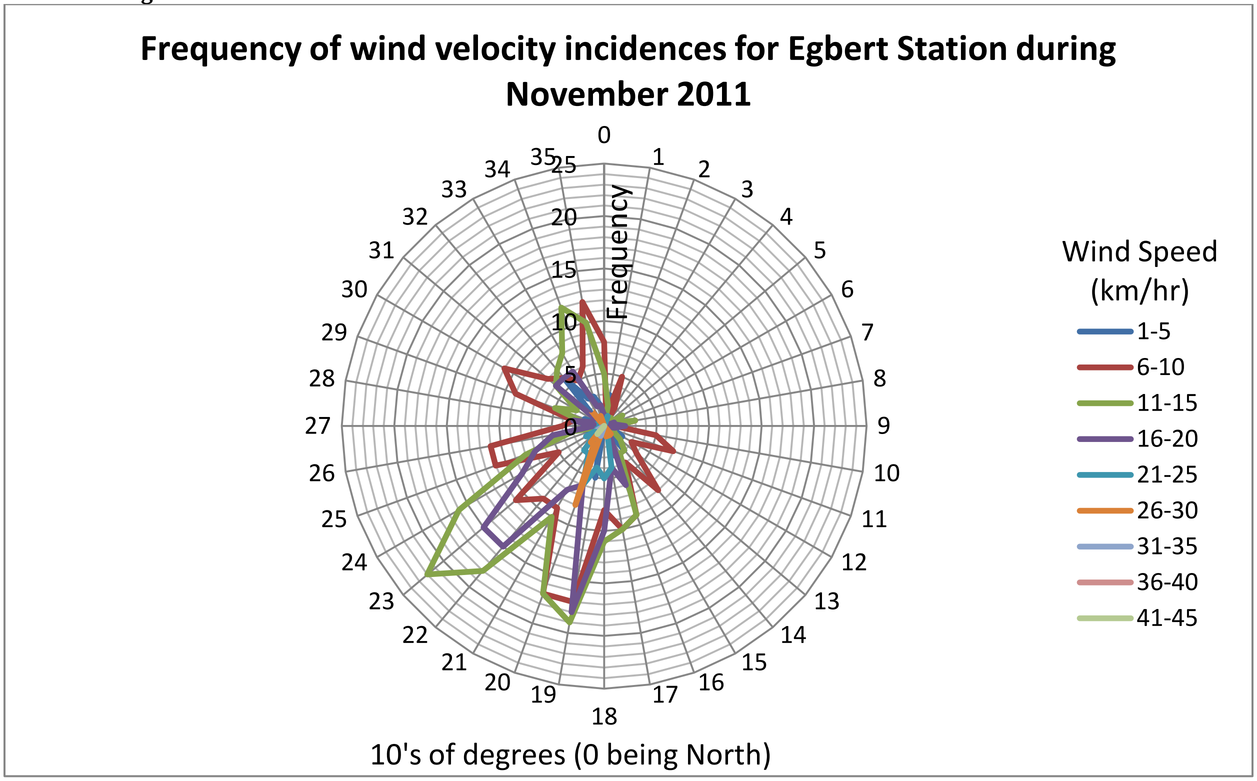

Figure 10.47: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during November 2011.

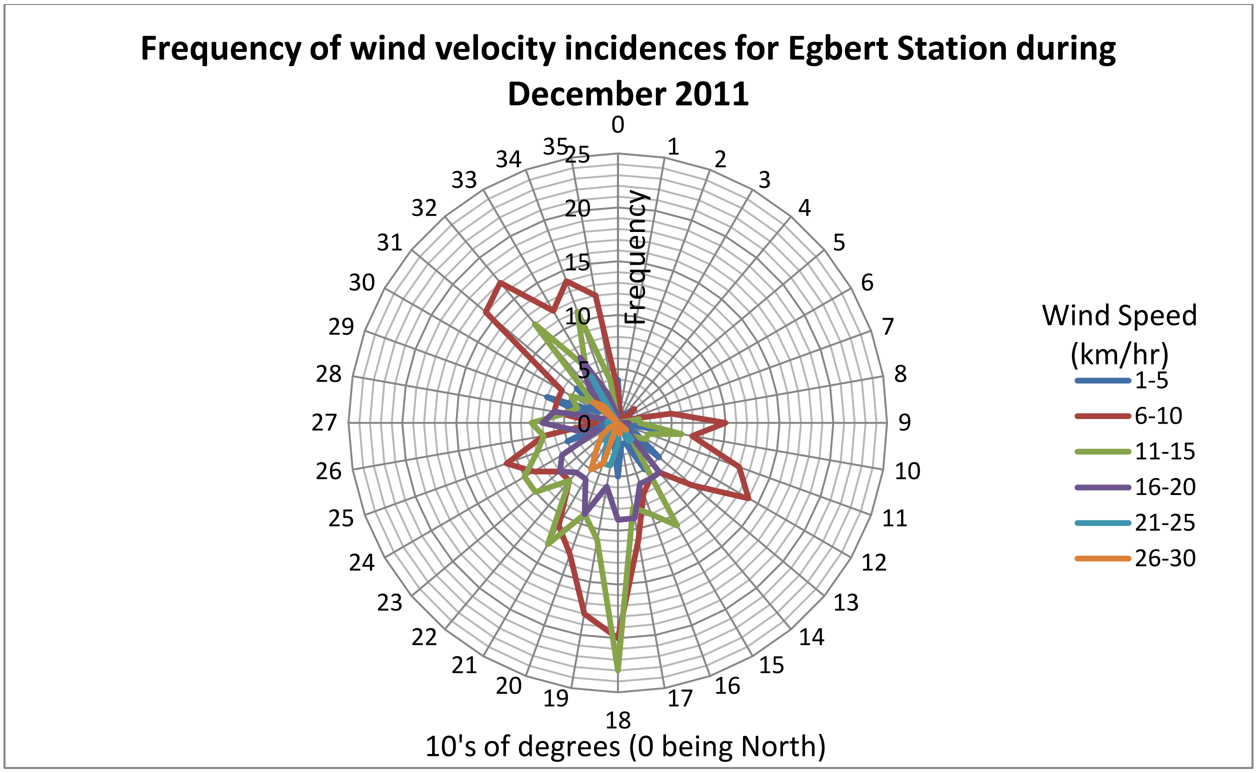

Figure 10.48: Wind rose graph of the frequency of wind speeds and directions collected at Environment Canada's Egbert Station during December 2011.

10.2 Precipitation Graphs

10.2.1 Precipitation Graphs for the Egbert Weather Station 2008-2012

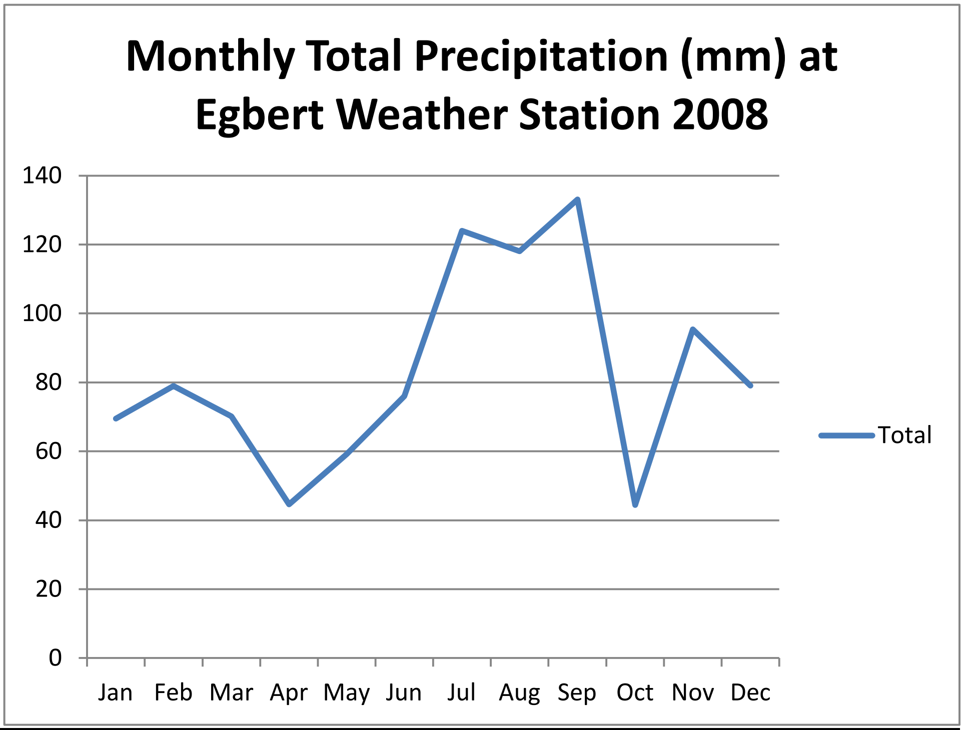

Figure 10.49: Monthly total precipitation (mm) at the Egbert weather station for 2008.

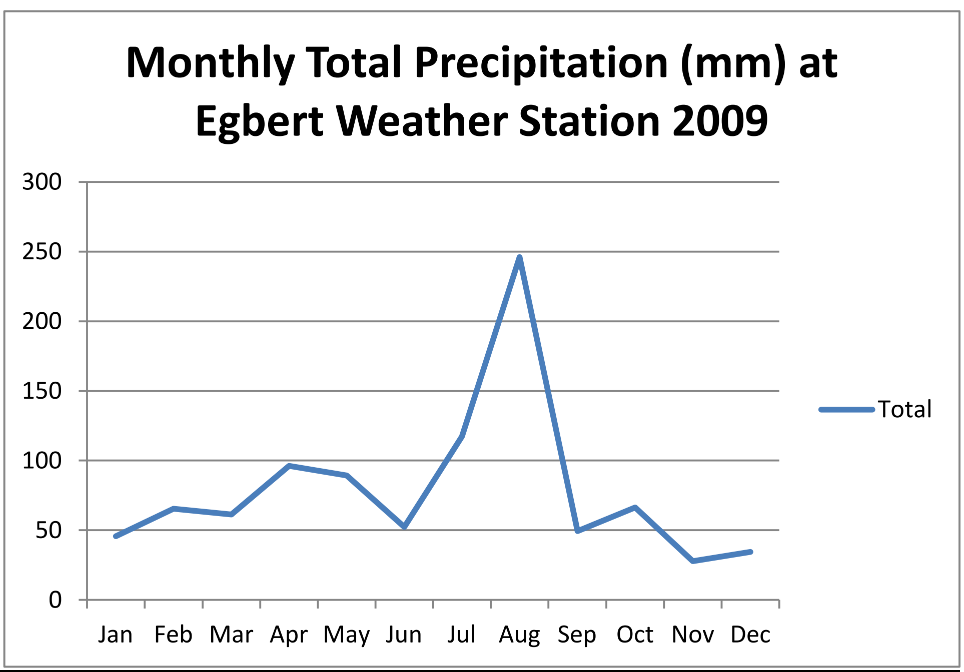

Figure 10.50: Monthly total precipitation (mm) at the Egbert weather station for 2009.

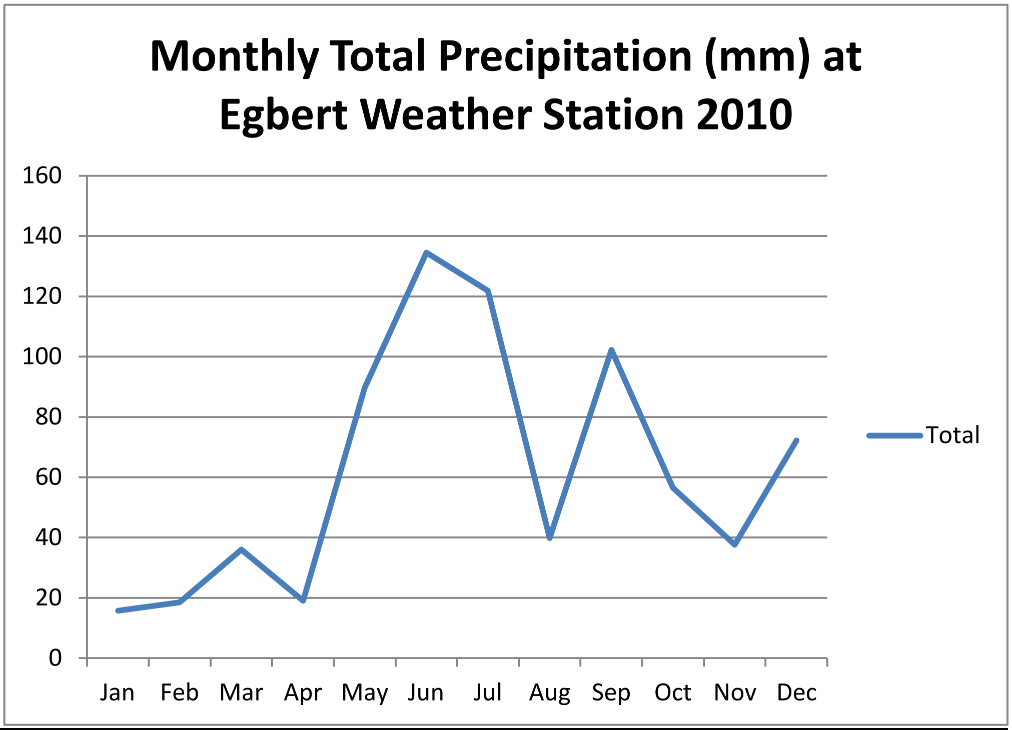

Figure 10.51: Monthly total precipitation (mm) at the Egbert weather station for 2010.

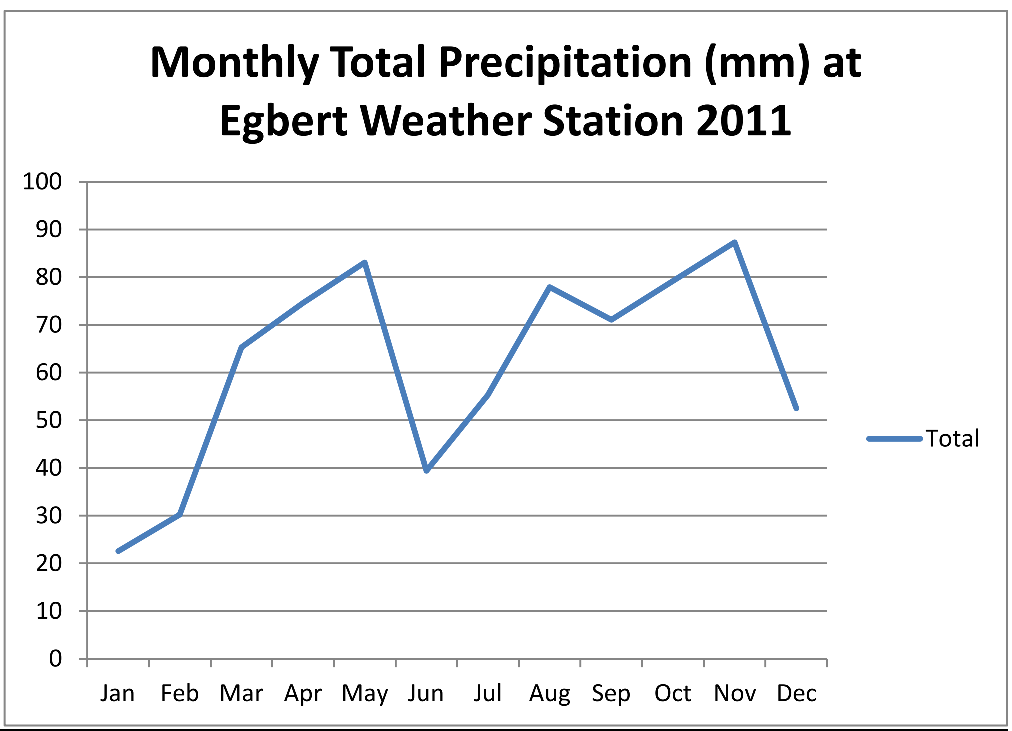

Figure 10.52: Monthly total precipitation (mm) at the Egbert weather station for 2011.

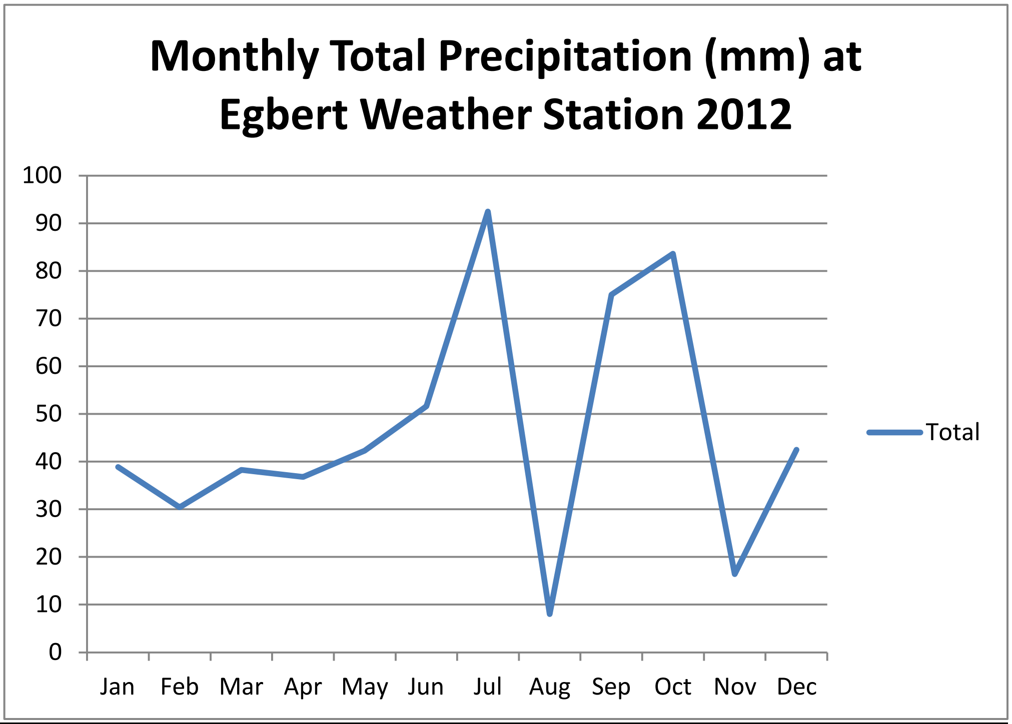

Figure 10.53: Monthly total precipitation (mm) at the Egbert weather station for 2012.

10.2.2 Precipitation Graphs for the Innisfil Golf Club 2010-2011

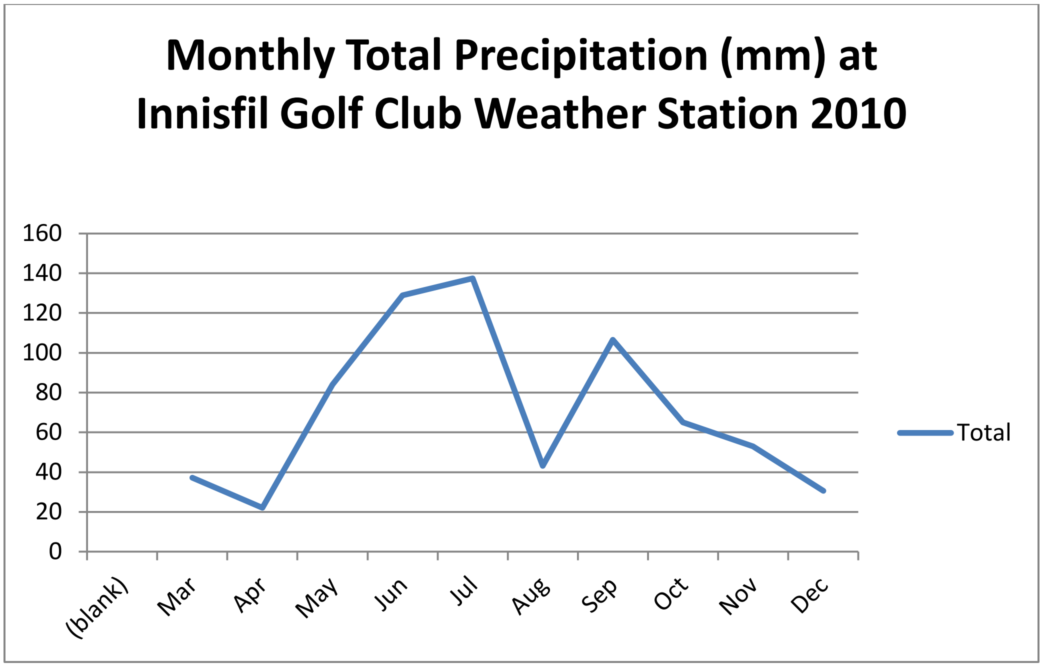

Figure 10.54: Monthly total precipitation (mm) at the Innisfil Golf Club for 2010.

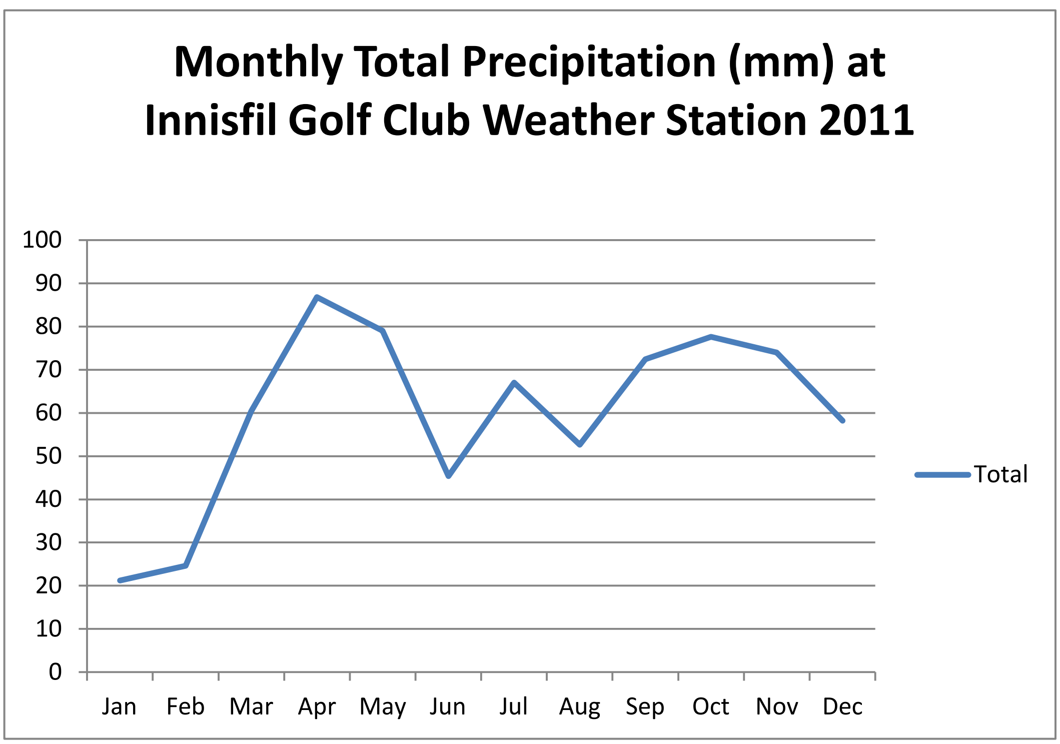

Figure 10.55: Monthly total precipitation (mm) at the Innisfil Golf Club for 2011.

10.2.3 Precipitation Graphs for the Mono Weather Station 2010-2011

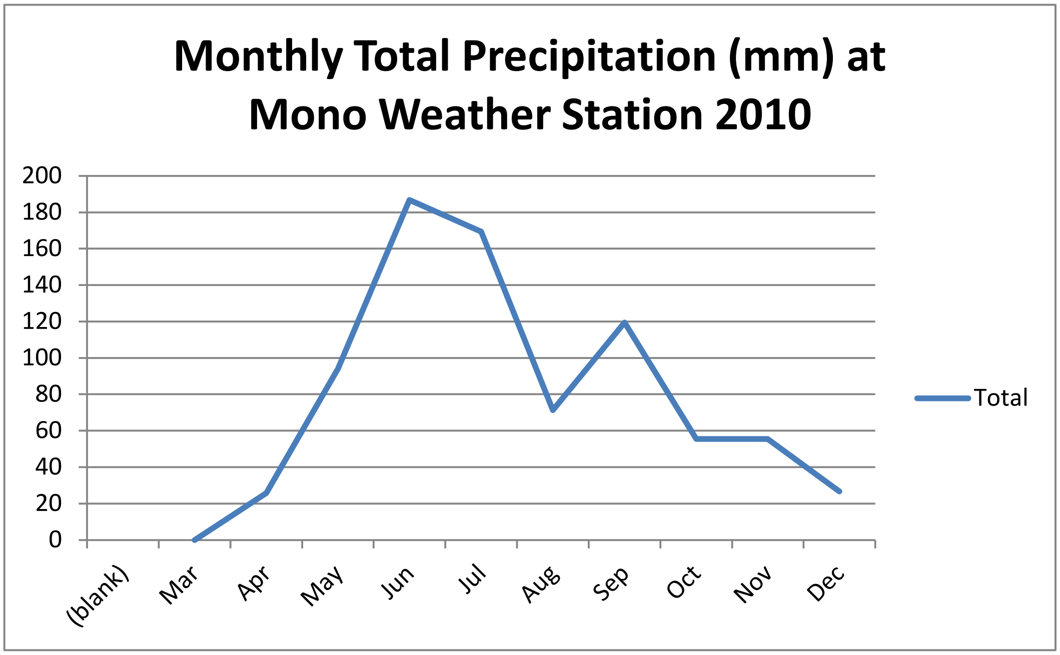

Figure 10.56: Monthly total precipitation (mm) at the Mono weather station for 2010.

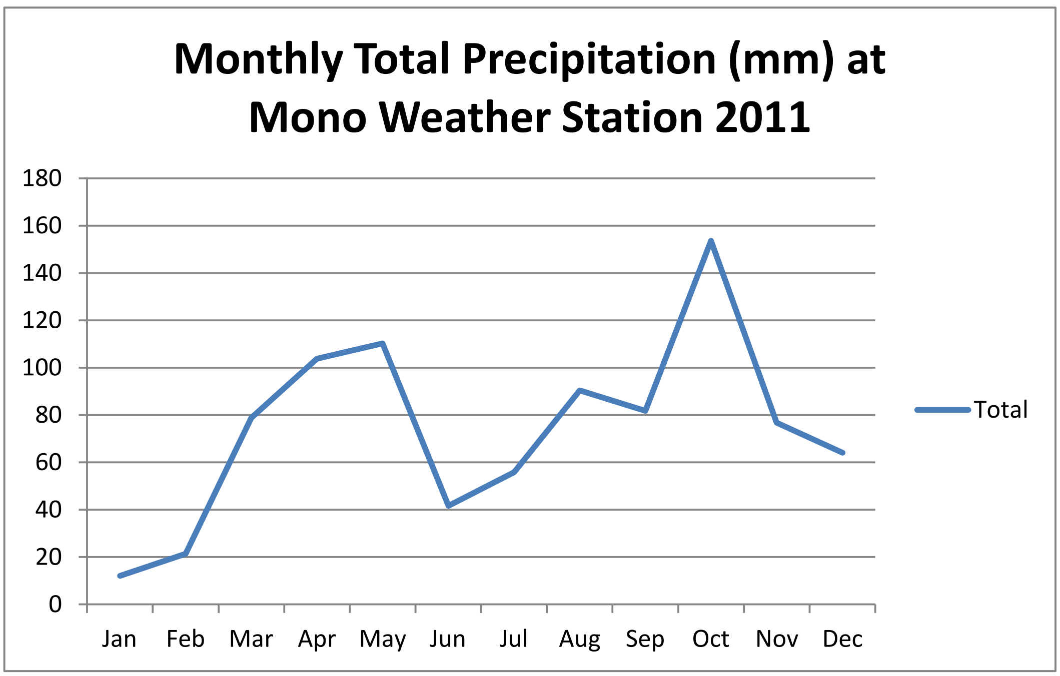

Figure 10.57: Monthly total precipitation (mm) at the Mono weather station for 2011.

10.2.4 Precipitation Graphs for the Oro-Medonte Weather Station 2010-2011

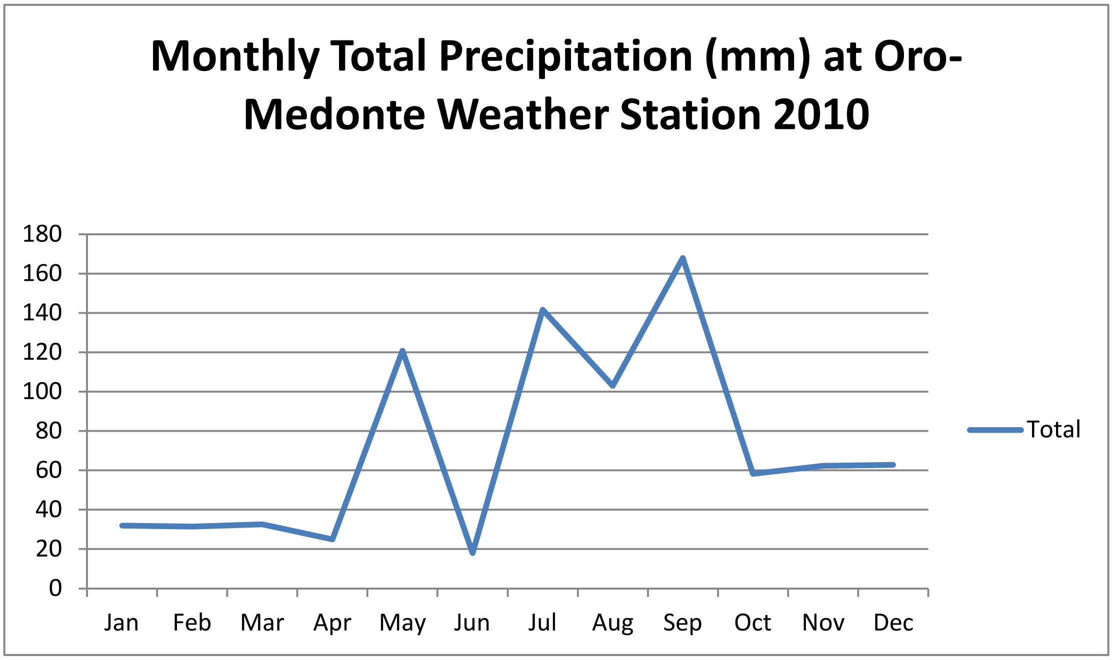

Figure 10.58: Monthly total precipitation (mm) at the Oro-Medonte weather station for 2010.

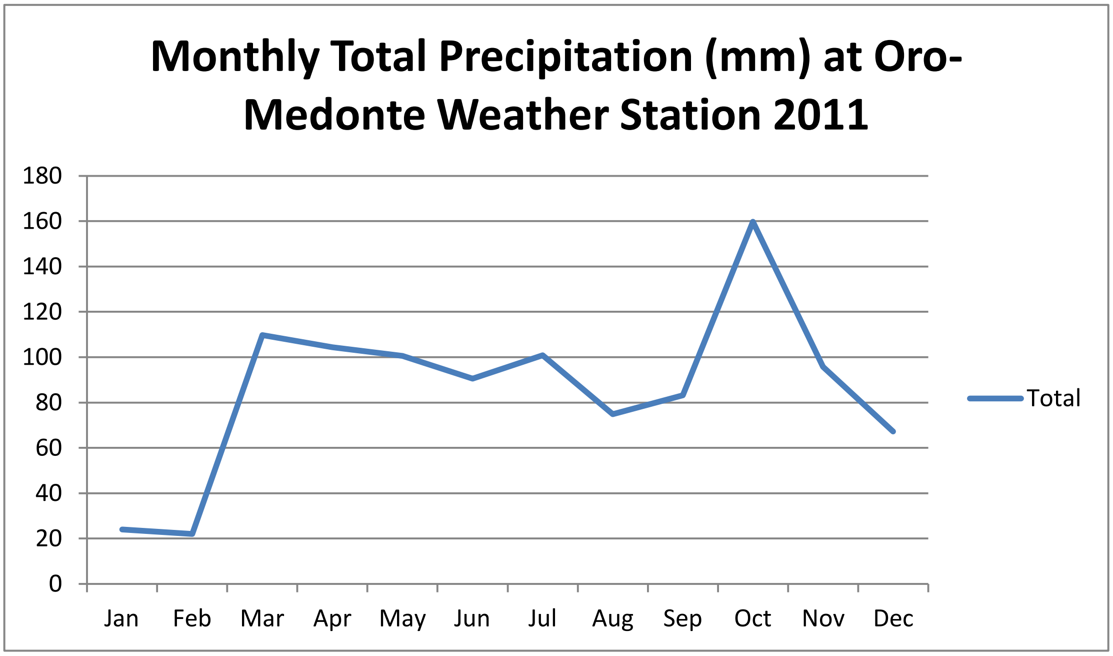

Figure 10.59: Monthly total precipitation (mm) at the Oro-Medonte weather station for 2011.

10.2.5 Precipitation Graphs for the Petun Weather Station 2010-2011

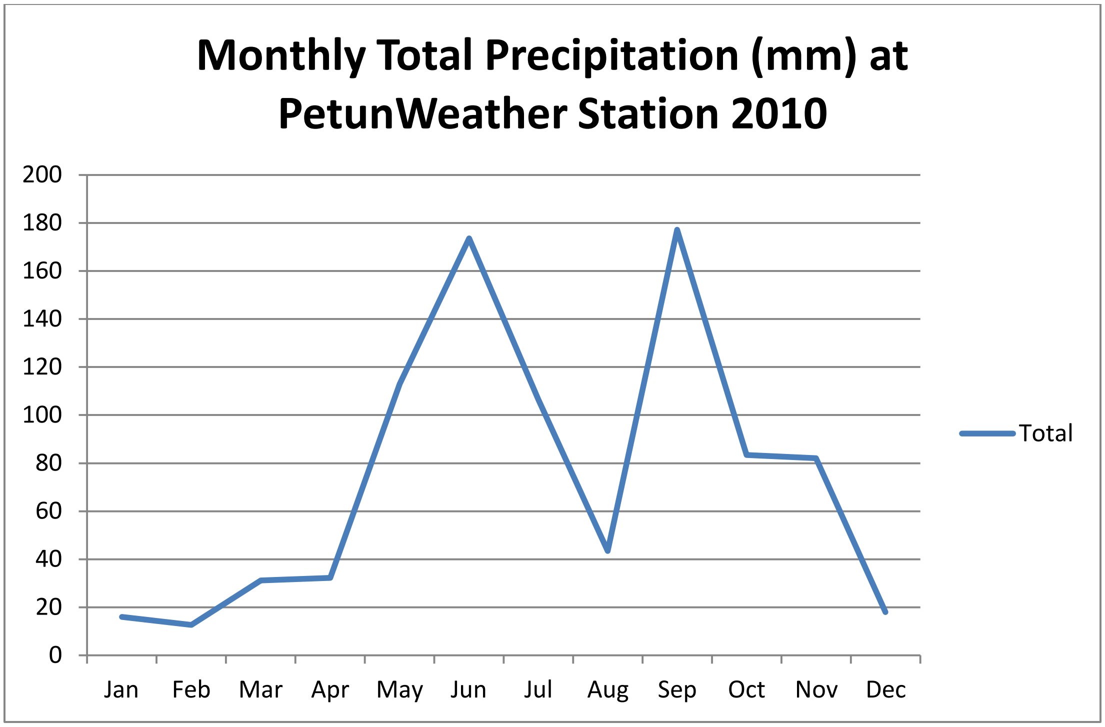

Figure 10.60: Monthly total precipitation (mm) at the Petun weather station for 2010.

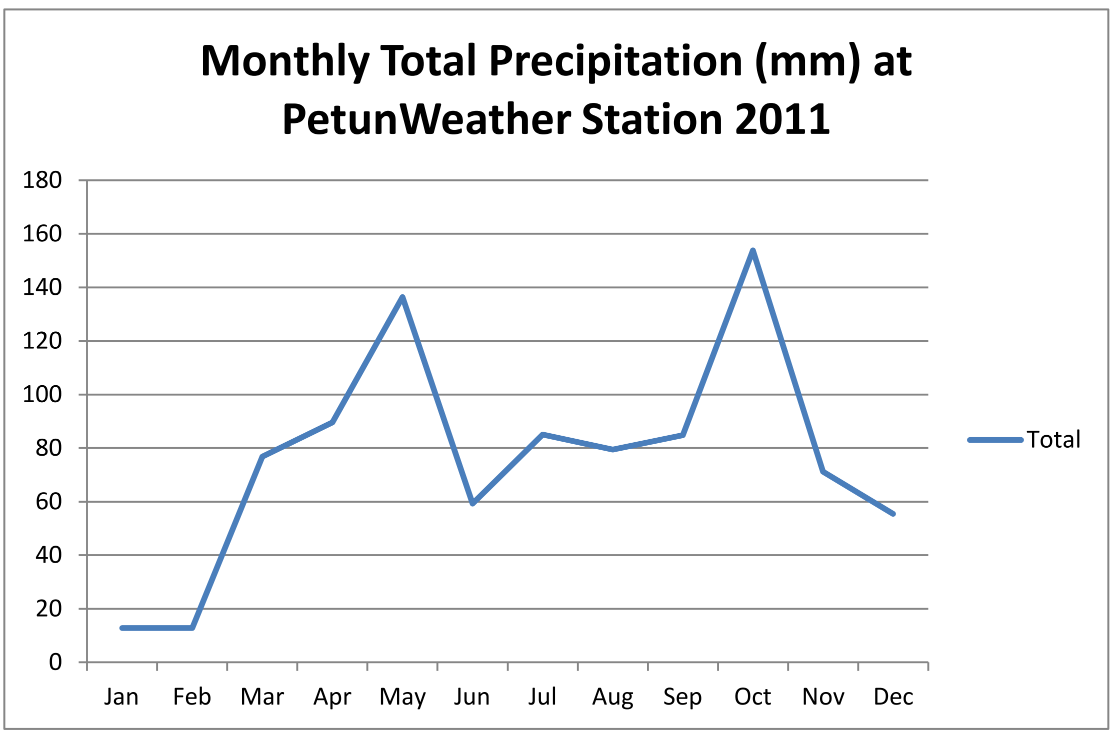

Figure 10.61: Monthly total precipitation (mm) at the Petun weather station for 2011.