CCIAP Project A-804
Impacts of Storms & Winds on Transportation in Southwestern Newfoundland

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1. Introduction

One of the key questions for transportation throughout Newfoundland is whether storm and wind activity is increasing, in frequency or magnitude or both. Other locations around the Atlantic Ocean have shown differing results, with some areas influenced by increased storminess and others showing no change over the past 50 years, thus making extrapolation to eastern Canada impossible.

All of the island of Newfoundland is dependent on maintaining regular Marine Atlantic ferry service through the harbour at Channel-Port aux Basques. All road traffic for the remainder of the island must pass along the Trans-Canada Highway from Port aux Basques northeast to Corner Brook through the Wreckhouse area, noted for its strong winds (“Wreckhouse Events”). At present, storm activity causes disruptions to ferry operations at Port-aux-Basques, with ships compelled to remain at anchor outside the harbour for two days or more, unable to dock until the wind subsides. During storm or wind events, transport truck traffic is unable to travel along the Trans-Canada Highway through the Wreckhouse area, as wind strength is sufficient to overturn large vehicles.

Increased storm severity and/or frequency would result in increased disruption to both ferry and road traffic. Without a better understanding of the likelihood of increases in either storm frequency or magnitude, Marine Atlantic and trucking operators are unable to adapt effectively to the uncertain impact of climate variability. This uncertainty ultimately affects all residents of Newfoundland who are dependent on this major land
and harbour transportation link. Transportation in this key region of southwest Newfoundland is thus vulnerable to disruption from both storm surge and wave-induced damage at the ferry terminal, and from wind events interfering with highway traffic.

1.1 Objectives

The objectives of this research directly related to marine storm events were:

- Assessment of the frequency and magnitude of extreme storm surges and high tide events in southwest Newfoundland
- Documentation of decadal- to century-scale change in sea level, storm surges, and extreme high tide events caused by climate change and variation
- Determination of the vulnerability of Channel-Port aux Basques, and the Marine Atlantic ferry terminal in particular, to future extreme storm surges and high tide events

The objectives directly related to highway transportation, as well as marine service, were:

- Assessment of the frequency, magnitude, and wind direction of extreme wind events in southwest Newfoundland
- Documentation of decadal- to century-scale change in extreme wind events caused by climate change and variation
- Determination of the vulnerability of transportation infrastructure in southwest Newfoundland to extreme wind events

Investigations to accomplish these objectives within CCIAP Project A-804 were divided into the following components:

1. Co-ordination and community liaison (Catto)
2. Geomorphic Impacts of Waves and Storms on the Southwestern Coastline of Newfoundland, including Port aux Basques Harbour (Catto, Ingram, Edinger)
3. Analysis of Tidal and Storm Surge record at Port aux Basques Harbour (Ingram, DeYoung, Catto, Edinger)
4. Record and Impact of Wreckhouse Events (Catto, Straatman, Foote, Kearney)
5. Climate and Meteorological analysis (Foote and Kearney, with contributions as acknowledged)
6. Economic impact analysis (Locke)

This report is organized to discuss each of these components. Chapter 1 introduces the study region. Geomorphic impacts of waves and storms on the coastline, and in Port aux Basques Harbour, are considered in Chapter 2. Analysis of the tidal and storm surge activity at Port aux Basques Harbour is presented in Chapter 3. The record and physical impacts of Wreckhouse events are discussed in Chapter 4. The climate and meteorological data are analysed in Chapter 5. Economic impact analysis is presented in Chapter 6. The results are summarized and discussed in Chapter 7.

1.2 Study Region

Investigation focused on the area of southwestern Newfoundland extending from Channel-Port aux Basques to Wreckhouse (Fig. 1.1, 1.2). The communities of Channel and Port-aux-Basques were amalgamated in 1945 to form a single community, officially named ‘Channel-Port aux Basques’ but commonly referred to as Port aux Basques. In 2001, the population of Channel-Port aux Basques was 4,637, an 11.6% decline since 1996 (http://www12.statcan.ca/english/profil01). The declining population reflects a general limitation of economic opportunity in southwestern Newfoundland, a trend which has continued since 2001 (Government of Newfoundland and Labrador, 2005).

Port aux Basques has served as a harbour since the early 1500s. It was chosen as the main ferry port and terminus for the Newfoundland Railway in 1898, and has served as the main surface entry point to Newfoundland since that time. Construction of the Trans-Canada Highway (completed in 1965) eventually rendered rail service redundant, with passenger service ceasing in 1971 and freight service in 1988. Port aux Basques
remains central to the Newfoundland economy, however, by virtue of its position at the terminus of the Trans-Canada Highway in Newfoundland, and as the only port which has year-round ferry service to the island.

Marine Atlantic operates a total of four ships between Port-aux-Basques and North Sydney NS (Figure 1.1). Currently, three large ferries (M.V. Caribou, M.V. Joseph and Clara Smallwood, and M.V. Leif Ericson) run continuously during the peak season (generally from June to September) and two remain in service for the whole year. The
Figure 1-2: Aerial photograph of Port-aux-Basques Harbour (circa 1983). Note the ferry docked at the wharf (top left) and the orientation of the breakwater structures (photo from Government of Newfoundland and Labrador).

*M.V. Atlantic Freighter* is dedicated to commercial traffic and freight, operating year-round. From 2000 to 2004, the service transported an average of over 434,000
passengers annually (Marine Atlantic, 2005), and in 2005, an estimated 500,000 people used Marine Atlantic’s ferry service through the port.

The Trans-Canada Highway extends northwestward from Port aux Basques, paralleling the coast. The small coastal community of Cape Ray is accessed from the highway, as is JT Cheeseman Provincial Park. Northwest of Cape Ray, the highway turns northeast, passing through the Wreckhouse area flanked by Table Mountain, Sugar Loaf, Cook Stone Hill, and Red Rocks Hill (Figure 1.3). The Wreckhouse area has been noted for its extremely strong wind events since initial construction of the Newfoundland Railway. Disruptions to rail service were recorded, with cars and engines forced off the tracks, and highway traffic is periodically disrupted at present. The Trans-Canada Highway leaves the Wreckhouse area south of the small community of St. Andrews.

The combined Port aux Basques – Wreckhouse route currently represents the major year-round surface transportation link between mainland Canada and the island of Newfoundland. It is the only link for highway traffic. Disruptions of this route, either by wave and storm surge activity at Port aux Basques or by strong Wreckhouse wind events, have resulted in severing the supply line to the remaining 500,000 residents of the island of Newfoundland, from St. Andrews to St. Anthony and St. John’s. Study of the potential for future interruptions resulting from weather events, climate variability, or long-term climate change, is thus of importance for all residents of the island of Newfoundland.

1.3 Present Regional Climate

Southwestern Newfoundland lies within the West Coast climate zone of the province (Banfield 1981, 1993; Damman, 1983). The area is under the influence of a cool humid mid-boreal climate (modified Köppen-Geiger Dfb), a consequence of the influence of the Gulf of St. Lawrence and the dominant southwesterly winds.

Climate data is collected in Port-aux-Basques by an automated weather station located approximately 1 km west of the harbour on Base Road, in the Mouse Island area (47° 34' N, 59° 09' W, 39.70 m asl; Environment Canada, 2005). Daily mean temperatures vary between -5°C in February and 15°C in August (Environment Canada,
**Figure 1-3:** Nautical chart of Port-aux-Basques Harbour. Note the breakwater structures and the narrow shipping lane (Canadian Hydrographic Service, 1998).
2005; Catto, 2002a, 2002c; Catto et al., 2006). Although mean February sea surface temperatures are less than 0°C along the entire coastline (Markham, 1980), development of sea ice is restricted (Cote, 1989), allowing all shorelines in southwesternmost Newfoundland to be affected by waves and storm surges throughout the winter (Catto, 1994a, 1994b, 2002a, 2002b; Ingram, 2004). The beaches of southwestern Newfoundland thus are subject to reworking and modification throughout the entire year.

Mean annual precipitation along the coastline is 1500 mm, with 1570 mm recorded at the Port aux Basques station (Environment Canada, 2005), of which 15-25% falls as snow (343 cm snowfall at Port aux Basques). Strong winds and periodic thaws limit the mean annual duration of snow cover to less than 70 days in coastal areas, although snow cover in the interior persists for up to 5 months annually. Statistically, the driest month is April (mean monthly precipitation 90-100 mm), and the wettest months are November and December (mean 140-155 mm during each). The combination of substantial precipitation and low summer temperatures, however, result in limited evaporation during the summer months. The excess of precipitation over evaporation locally exceeds 100% during some summers, as well as throughout the winter months, creating a perhumid moisture regime and allowing wetlands to develop.

During the spring and summer, from March to August, the prevailing winds are easterly. During the autumn and winter, from September to February, the prevailing direction is from the west. The mean annual wind speed is 24.4 km/h (Environment Canada, 2005) and higher magnitude wind events are common. According to the 30-year Canadian Climate Normals, an average of 69.5 days per year experience winds exceeding 52 km/h and an annual average of 33.6 days experience winds in excess of 63 km/h (Environment Canada, 2005). Easterly winds tend to have the greatest influence on ferry traffic into Port-aux-Basques Harbour, and are also primarily responsible for triggering Wreckhouse wind events.

Detailed discussion of the data related to potential patterns of climate variation and change over the past 50 years is presented in Chapter 5 of this report.
1.4 Harbour Configuration and Port Infrastructure

Port-aux-Basques Harbour is open to the southeast, with an embayment extending northeastward at its head, and is approximately 2 km² in area (Figure 1.2, 1.3). The mouth of the harbour is 900 m wide at the seaward limit. The southeastward orientation makes the harbour susceptible to winter easterly storms. This vulnerability has been mitigated with the construction of a breakwater, consisting of two separate sections, confining the opening midway through the channel. At its narrowest point, the channel opening is less than 400 metres wide (Figure 1.3). The effectiveness of the breakwater is enhanced by the presence of two natural islands, Vardys Island situated in the centre of the inner section of the harbour, and Pikes Island to which the breakwater is joined. The two islands form important buffers to wave action.

The Marine Atlantic ferry terminal is located at the northwestern corner of the harbour, on the former Ford’s Island, which has been connected to the mainland to make room for the terminal infrastructure. To the east of the ferry terminal, and along the eastern shore, the harbour is largely undeveloped. To the south of the terminal, extending outwards in the harbour, the shoreline has been extensively developed. Numerous wharves, including the Federal Government Wharf, Ring Bolt Cove Wharf, a recreational board walk outfitted with a performance stage and concession stands, the Port-aux-Basques Harbour Authority Wharf, and the local fish plant facilities are present. Additionally, the outer area of the harbour is lined with private property with homes constructed very close to the shoreline; some only 1 m above the high water line.

The harbour underwent major infrastructure development and improvement in the 1950s in preparation for larger ships and increased traffic. Along with the construction of a new terminal building, the parking area was expanded and a new wharf and breakwater were built. The L-shaped pier had a total length of 317 metres and enabled the simultaneous docking of the southern Newfoundland coastal boats, servicing Burgeo and ports east, and the larger Nova Scotia ferries (Windsor, 1956). The harbour was dredged in 1953.

Construction of the breakwater was completed in July 1956. The structure was assessed to have essentially eliminated undertow in the docking area, and overall docking conditions at the pier were estimated to have improved by 40%. The breakwater extends
134 m across the harbour and is 21 m wide. At the end of the structure the water is more than 10 m deep. The breakwater rises about 6 m above the waterline (Windsor, 1956).

**Figure 1-4:** Port-aux-Basques Harbour looking southeast. Note the breakwater extending across the harbour and a section of the Marine Atlantic dock in the foreground. Vardys Island is to the left and to the right is the Transport Canada vessel traffic tower and headquarters (photo taken June 2005).

**Figure 1-5:** The town of Channel Port-aux-Basques and the west side of the harbour. Note the ship (*M.V. Atlantic Freighter*) docking at the Marine Atlantic ferry terminal and the proximity of some of the homes to the ocean. (photo taken June 2005).
Figure 1-6: Topographic map of the Port-aux-Basques area. The locations of the automated tide gauge and climate station are identified with yellow circles and labelled (Geomatics Canada, 1986).
2. Geomorphic Impacts of Waves and Storms on the Southwestern Coastline of Newfoundland, including Port-aux-Basques Harbour

Norm Catto, Dan Ingram, Evan Edinger

2.1 Introduction: Storm surges and sea level rise

Newfoundland, including the southwest coast, has been subjected to many significant storms, resulting in property destruction (Forbes et al., 2000; Catto et al., 2003; Catto and Hickman, 2004; Catto, 2006b). Hurricane Juan (2003), the most economically destructive hurricane event in Atlantic Canadian history, killed eight people and was responsible for at least $200 million in damage to Nova Scotia and Prince Edward Island (Environment Canada, 2004). Historical events, such as the Great Hurricane of 1775 in eastern Newfoundland (Stevens and Staveley, 1991; Stevens, 1995; Ruffman, 1995) provide ample evidence of the impact of extreme storms and storm surges.

The effectiveness of any particular storm at a location depends upon the angle of wave attack, the number of previous events during the season, and other local factors. Adjacent beaches can exhibit very different responses to a particular storm, as was evident on southwestern Newfoundland beaches impacted by Hurricanes Gustav (2002) and Frances (2004). Beaches separated only by a headland varied widely in the amount of geomorphic response to storms (e.g. Catto et al., 2003).

The northern Atlantic Ocean has been undergoing an increase in hurricane frequency and magnitude since 1995 (Goldenberg et al., 1997, 2001; Landsea et al., 1998; Debernard et al., 2002; Emanuel, 2005; Webster et al., 2005). However, the relationship between changes in hurricane frequency and magnitude, and increases in air temperature or sea surface temperature (SST), is not clear at present, and consensus does not exist. Although causal links between SST changes and hurricane frequency and strength have been suggested (e.g. Sugi et al., 2002; Trenberth et al., 2003; Knutsen and Tuyela, 2004; Trenberth, 2005), other researchers have expressed reservations and recognized uncertainties (e.g. Swail, 1997; Shapiro and Goldenberg, 1998; Pielke et al., 2005; Webster et al., 2005). Regardless of the uncertainty of future changes in hurricane
frequency and magnitude in response to climate change, it is apparent that the North Atlantic is currently undergoing a period of increased hurricane activity.

A storm surge is defined as the elevation of the water resulting from meteorological effects on sea-level (Murty, 1984; Pugh, 1987). The storm surge elevation is the difference between the observed water level during the storm and the level that the astronomical high tide would normally rise to in the absence of storm activity (Forbes et al., 2004). The Port-aux-Basques area has experienced surges of a variety of magnitudes, including several large ones, over the past 100 years. The return time of a surge that exceeds 1 m is approximately 10 years, and every 50 years a surge will occur that exceeds 1.5 to 2 m (Charles O’Reilly, personal communication). The full effect of a surge may not be experienced unless it coincides with high tide, particularly a high spring tide. Storm surges are associated with both winter storms (e.g. January 2000) and summer tropical storm systems (e.g. Hurricane Gustav, 2002).

Rising sea level allows waves and storm surges to penetrate further inland, modifying beach morphology and sedimentology and resulting in both coastal erosion and damage to infrastructure. The observed changes in sea level result from the interplay of climate change, involving melting of the polar glaciers, thermal expansion of the ocean, and consequent increase in the water volume in the oceans, with isostatic response to past glaciation. With the exception of northernmost Labrador and Lake Melville, Atlantic Canada is now subsiding, resulting in relative sea level rise, transgression and flooding by the ocean.

Short-term (decades) changes in sea level can be assessed through study of tide gauge records. At Port aux Basques, the tide gauge record from 1960 through 2005 indicates a mean rate of sea level rise of approximately 3.3 mm/a (Fig. ccc). This rate is comparable to those observed at Charlottetown and Halifax (e.g. Shaw et al. 1998, 2001; Bruce, 2002; McCulloch et al., 2002) and in eastern Newfoundland (e.g. Catto, 2006b, 2006c; Catto et al., 2003). Evidence of marine transgression is reflected by enhanced erosion along many Atlantic Canadian beaches, including those to the northwest of Port aux Basques (Catto, 2002) and in the Burgeo area (Ingram, 2004), and inundation of terrestrial peat deposits and trees.
In low-lying areas with coastal development, erosion and flooding are significantly increasing and will continue to increase (Daigle et al., 2006). Consideration of the geological factors, rate of sea level rise, amounts of coastal erosion, wave climate, and tidal regime allow calculation of the sensitivity to sea-level rise of shoreline segments (e.g. Gornitz et al., 1993). This assessment has been completed for Atlantic Canada as a whole on a broad regional scale (Shaw et al., 1998), and more detailed assessments have been conducted for specific segments of the coastline (e.g. Chmura et al., 2001; Catto et al., 2003; Daigle et al., 2006; Shaw, 2006). The observed sea level rise in Atlantic Canada, and the projected rise for the future, depends upon the interaction between the changing volume of the oceans and glacioisostatic activity.

### 2.2 Storm Surge Events in Southwestern Newfoundland

The coastline of southwestern Newfoundland has been subject to at least 5 storm surge events since January 2000. The largest of these was the storm surge of 21-22 January 2000, associated with the same event that caused substantial damage in Prince Edward Island and New Brunswick (Forbes et al., 2000; Bruce, 2002; McCulloch et al., 2002; Parkes et al., 2006). Among others, lesser surge events resulted from Hurricane Gustav (12 September 2002) and Hurricane Frances (2 September 2004).

The largest storm surge in recent years to affect the Port aux Basques region occurred on 21-22 January 2000. Unfortunately, the precise magnitude of the surge cannot be determined in Port aux Basques Harbour, as the tide gauge was out of service at the time (see discussion in Chapter 3 and Ingram, 2005).

This event caused extensive damage and was the worst storm to hit the region since 1974 (Bateman, 2000; Ryan 2000). The peak sustained wind velocity was recorded at 96 km/h at 1:30 a.m. NST on 22 January, with a maximum gust of 137 km/h. During this time, a wave-ride buoy recorded waves offshore to be approximately 15 m in height. Environment Canada meteorologist John Macphee conducted a field assessment of the Port aux Basques area following the event, and estimated that a rogue surge wave of about 18 m height hit the community at around 3:00 a.m NST (Macphee, personal communication; Bateman, 2000; Ryan, 2000).
The surge primarily impacted the Channel Head area of the town and caused the greatest extent of damage. Homes received considerable damage, including flooding and the removal of siding and roofing shingles. Vehicles were damaged by flying debris and inundation, and exterior structures were destroyed. The 8 tonne Fisheries & Oceans Canada mariner fog alarm buoy was shifted more than 1 km into the harbour. Coast Guard equipment mounted on Channel Head received damage extending to 21 m asl, suggesting that the wave impacted at ca. 16-18 m elevation, with salt spray extending a further 3-5 m upward. Severe destruction to the walkways and other equipment at the Coast Guard installation, however, at about 18 metres above sea level, was directly caused by the wave (Bateman, 2000; Forbes et al., 2000; Ryan, 2000).

Overall, residential damage for this surge event alone totaled at least $280,000. Damage to municipal infrastructure, primarily the sewage outfalls, was assessed at over $400,000 (Bateman, 2000; Municipal and Provincial Affairs, 2000). The total economic damage figure was estimated at more than $1 million (Len LeRiche, Public Safety and Emergency Preparedness Canada, personal communication).

The actual monetary costs of disasters are always greater than the quoted values. Reported figures are commonly the direct cost of the buildings, property, and public infrastructure (The H. John Heinz III Centre, 2000; Kumar et al., 2001; Parson et al., 2003). Discrepancies between insured values, personal expenses covered by government compensation, and the actual or replacement value of the property lost can be significant (Kreibich et al., 2004; Hickman, 2006). Monetary values of buildings and infrastructure are readily determined, using assessed values for taxation or insurance. Property located outside buildings, such as vehicles, is frequently not covered in total value by government compensation programs or private insurance. Damage to exterior property, uninsured items, and indirect costs are not included in the monetary values or damage estimates quoted, especially those announced within a short time after the event.

The economic impacts of a disaster may continue for years after the event. Damaged infrastructure may fail earlier than its designed lifespan (Kumar et al., 2001). Prolonged health care and psychological counseling can be required for victims and responders (Milne, 2002; Tapsell and Tunstall, 2003).
Hickman (2006) conducted an assessment of costs resulting from flood damage in selected Newfoundland communities, and noted that indirect costs substantially outweigh those resulting solely from damage to infrastructure. In June 2005, the cost of the January 2003 flooding at Badger NL was estimated at $8.2 million (Paul Peddle, EMO NL personal communication). This figure is more than 25 times the original estimate of potential physical damage estimated by FENCO (1985), corrected for inflation, although the 2003 flood waters reached almost exactly the elevation assumed in the 1985 study. Much of the difference is represented by more accurate assessment of indirect costs not associated with immediate response, rescue, and restoration of structures to pre-flood conditions.

Hickman (2006) calculated that the March 2003 rain-on-snow flooding event in Corner Brook, which resulted in $1.4 million in direct (recorded and announced) damages, actually had an economic impact on the order of $5 million, although no deaths or serious injuries resulted. Similar recorded damage totals resulted for the Burin Peninsula from the impact of Hurricane Luis (1995) and for Torbay for Tropical Storm Gabrielle (2001).

The actual costs of the flooding events studied in Newfoundland were more than twice the reported figures in all instances. Applying a similar standard to Port aux Basques would suggest that the actual financial impact of the 21-22 January 2000 storm surge event would approach $3 million. This figure does not account for any losses resulting in disruption to transportation between Port aux Basques and the remainder of Newfoundland.

Social and community impacts of disasters are difficult to quantify. They are commonly not recorded in estimates of ‘total cost’ of flood damage, which tend to be expressed in monetary terms. Flooding hazards may impact individual perceptions of personal security, producing stresses that are not directly expressed in monetary terms. For community residents these impacts are as relevant as quantitative costs, and may be more lasting.

The potential impact of a storm surge on Port aux Basques was the subject of an exercise for municipal officials, first responders, emergency measures personnel, and other responsible individuals on 13 June 2006 (see Seguin et al., 2006).
Prior to the January 2000 surge event, the most recent comparable surge occurred on 20 October 1974. Logged water-level, atmospheric pressure, and wind data were examined (Ingram, 2005). During this event, peak winds gusts reached the same maximum as in the 2000 storm (137 km/h) and the maximum sustained winds were 84 km/h. Extensive damage was caused, including the destruction of the helicopter pad at Channel Head. Sections of railway track along the coast at Osmond and north of Cape Ray were damaged by waves and surge, which subsequently caused the derailment of two diesel locomotives as they attempted to negotiate the damaged track (Bateman, 2000).

The lesser storm surge events which occurred in association with Hurricanes Gustav (2002) and Frances (2004) primarily impacted the sand-dominated beach systems at Grand Bay and JT Cheeseman Provincial Park, northwest of Port aux Basques. The times of storm landfall on both occasions did not coincide with astronomical high tide, reducing the storm surge heights. No damage was noted to installations in Port aux Basques Harbour, although erosion of the dune-backed coastlines was notable following Gustav.

The relative timing of storm surge events with respect to astronomical high tide is critical. Hurricane Gustav did little damage in Charlottetown PEI, primarily because the storm surge coincided with a lower tidal position, approximately 4 hours before astronomical high tide. Environment Canada noted that if the storm surge had coincided with high tide, water levels would have been comparable to those recorded during the January 2000 event (http://www.atl.ec.gc.ca/weather/hurricane/gustav02_e.html), which brought widespread flooding. Storm surges induced by hurricane activity thus are potentially significant at Port aux Basques.

2.3 Tsunamis

Tsunamis are the products of seismic activity, and are not related to climate. However, their potential impact on the southwest Newfoundland coastline is similar to that for storm surges.

The 1929 Burin Tsunami killed 28 people in Newfoundland and 1 in Cape Breton, a greater death toll than for any other Canadian seismic event (Ruffman, 1991, 1993, 1995a; Fine et al., 2005). The impact of the tsunami was felt along the south coast of
Newfoundland, from the Burin Peninsula west to Port aux Basques, although all the Newfoundland deaths and almost all of the destruction occurred along the Placentia Bay shore of the Burin Peninsula. Runup heights reached 13 m asl (Fine et al., 2005). Some damage was noted to fishing vessels, stages, and gear in Burgeo, but there were no injuries. The occurrence of other tsunami events, notably in 1864 at St. Shotts (Avalon Peninsula) has been suggested (Ruffman 1995a, 1995b), but these have not been verified, either by historical accounts or through geological studies.

Preliminary investigations at Burgeo have not revealed the distinctive tsunami laid sands (TLS) that commonly mark landfall areas for tsunamis, both on the Burin Peninsula (e.g. Ruffman, 1993; McCuaig and Bell, 2005) and elsewhere (e.g. Dawson, 1999). However, TLS deposits are generally preserved in isolated lagoons, salt-water marshes, and other low-energy environments not influenced by repetitive wave erosion. The lack of suitable preservation areas at both Burgeo and Port aux Basques Harbour means that TLS deposits would not be expected to be preserved, even in areas that were known to have experienced tsunami activity.

The occurrence of the Burin Tsunami demonstrates that tsunami waves, of comparable elevation to the largest waves associated with storm surges, could strike the coastline in the Port aux Basques and Burgeo areas. The total damage to property on the Burin Peninsula was estimated at about $1 million in 1929 dollars (Liverman et al., 2001), equivalent to ca. $11 million in 2006. This figure, however, must be regarded as an extremely low estimate. In addition to the difficulties involved in estimating the actual costs of damage from natural hazards, as alluded to above, the infrastructure destroyed along the Burin Peninsula in 1929 consisted largely of wooden stages, small fishing vessels, and houses. A comparable event today would result in much greater monetary loss.

2.4 Coastal Erosion

The sensitivity of a coastline to erosion is governed by the energy and frequency of wave action, and by the physiography and geological composition of the coastal zone. The majority of the southwestern coast of Newfoundland lies within the Newfoundland Uplands of Appalachia (Bostock, 1970). Eastward from Port-aux-Basques to Burgeo,
fjard morphology characterizes the shorelines developed on Palaeozoic granite and associated igneous rocks (Riley, 1959; Dickson et al., 1996), with irregular embayments, numerous skerries and small islands. Embayments are variable in depth, with irregular profiles influenced by differential pre-glacial weathering and glacial scouring. This area is generally resistant to coastal erosion, except where accumulations of sand backed by coastal dunes are present, as at Sandbanks Provincial Park (Catto 2002, 2006a; Ingram 2004). Burgeo Harbour, flanked by exposed granite, is not subject to coastal erosion, even during storm surges.

Metamorphosed Palaeozoic units (Port-aux-Basques schist, van Staal et al., 1996) underlie the coastline extending northwestward from Port-aux-Basques to J.T. Cheeseman Provincial Park and Cape Ray Cove. The structural weaknesses and lithologic divisions in the metamorphic units generally trend NE-SW. Erosion, both by coastal and terrestrial processes, has exploited the planes of weakness, creating a shoreline marked by shallow coves separated by rock spurs aligned parallel to the geological structure. This alignment mirrors that of the prevailing winds of the area, resulting in topographic funneling of waves into embayments.

In areas where bedrock is exposed, such as Port aux Basques Harbour, weathering is confined to terrestrial processes, primarily frost action. The coastline is not subject to erosion by waves, even those resulting from hurricanes and storm surges.

Erosion has affected the dune-backed coastlines of Grand Bay West and JT Cheeseman Provincial Park, northwest of Port aux Basques, and Sandbanks Provincial Park, near Burgeo. Along the Gulf of St. Lawrence coast of Newfoundland, the combination of rising sea level, increased human utilization of the coast for tourism purposes, and limited offshore winter ice conditions have resulted in accelerated erosion and degradation of the dunes and coastline (Pittman and Catto, 2001; Catto, 2002a, 2006b; Ingram 2004). Ingram (2004) noted erosion at the rate of 0.7 m per month between December 2003 and April 2004 at Sandbanks Provincial Park, concentrated in the late summer-autumn period, and in early winter before freezing of the beaches occurred, providing some measure of protection. This rate of erosion represents a substantial acceleration from previous estimates (Catto, 1994).
Figure 2.1: Coastal Erosion at Sandbanks Provincial Park, Burgeo. View looking to the northwest at the mid-section of the beach, 9 April 2004 (Dan Ingram)

Figure 2.2 Sand-dominated beach and backing dune, JT Cheeseman Provincial Park, showing mobilization of coarse clasts, evidence of recent storm-surge erosion.
The impacts of climate change and variation, storm events, and human activity on J.T. Cheeseman and Sandbanks Provincial Parks, and the impact on Piping Plover (*Charadrius melodus*) have been discussed in detail elsewhere (Catto, 2002a, 2002b). A summary of the principal findings of these previous investigations is presented here.

In southwestern Newfoundland, coastal dune development and associated sandy beach evolution is related to destabilization of littoral areas initiated by marine transgression (Catto, 1994; Catto, 2002a). Consequently, rising sea level, ca. 3.3 mm/a, is acting to destabilize the coast, increasing vulnerability to coastal erosion and storm surges. The beaches of southwestern Newfoundland are subject to reworking and modification throughout most or all of the year. The coastline typically remains entirely ice-free until February, and during some years, it may remain ice-free throughout the winter.

Removal of overlying fine sand has exposed underlying hard-packed medium grained sand, and storm-transported shell hash, coarse sand, granules, and fine pebbles now overlie many areas. Storm-driven waves have resulted in bank erosion in some areas of the dune complex at JT Cheeseman in excess of 1 m between summer 1999 and June 2002 (Catto, 2002a, 2002b). In addition to changes in grain size distribution resulting from fluctuating longshore drift, storms, snow cover, aeolian activity, and humans also cause changes in the sediments exposed on the beach.

Regional changes in temperature and precipitation are only secondarily responsible for dune modification and erosion. Boreal conditions prevailed from mid- to latest Holocene in southwestern Newfoundland (see Davis *et al.*, 1987; Davis, 1993; Anderson and Macpherson, 1994; Macpherson, 1995). The sedimentary structures within the dune sequences throughout southwestern Newfoundland indicate that formative processes remained similar throughout the period of dune accumulation. In the absence of detailed chronological investigations, there is no evidence to suggest any substantive or consistent change in formative processes over time. Local climate conditions governing sediment flux, and human disturbance of the dunes, are more significant than are broad changes in regional climate.
The available information for southwestern Newfoundland suggests that any summer warming trend may be offset by increasing summer precipitation, and the overall perhumid moisture regime is not expected to vary significantly under current climate change scenarios (Lewis, 1997; Lines et al., 2003). Future conditions would not be optimal for sand dune formation or expansion. Limited sand remobilisation from dunes to coast over a long period will lead to gradual coarsening of the beaches. If beaches are deprived of sand from longshore transport, there is no ready source of sand from stabilized dune fields, and consequently the coarsening process will be accelerated under storm wave reworking. As dunes and beaches are linked parts of a system, a reduction in dune mobility results in a decrease of sand availability for beach maintenance. This could have an impact on tourist utilization and perception of the beach systems (Catto, 2004).

The high winds associated with storms are accompanied by precipitation, which simultaneously diminishes their effectiveness in eroding the higher dunes. Storm winds are most effective at eroding previously existing trough and linear blowouts, and are relatively ineffectual at eroding windward surfaces. In undisturbed areas, the strongest storm winds tend to sweep across the dune surface, and may result in accretion where small saucer blowouts are infilled by grainfall deposits upon quiescence.

The primary effect of storm activity on the dunes is to destabilize the dune surfaces, rendering them vulnerable to anthropogenic disturbance. By removing vegetation and sweeping debris from linear blowout bases, the storm winds create freshly exposed surfaces that are subsequently available for human reworking. The propagation of linear blowouts is facilitated by the strong storm winds, thus widening and deepening the tracks and making them more attractive for human foot traffic. The storm winds also rework and deepen deflation hollows. Deflation hollows influenced by anthropogenic bonfires and quarrying are particularly susceptible to deepening and widening during storms.

Natural impacts are related primarily to storm winds, waves, and surges. The decrease in sediment influx from the dunes also plays a role, and the slowly rising sea level has a lesser influence. These processes have resulted in erosion, coarsening of
sediment along the shoreface, and a gradual steepening of the beach profile. The natural effects are currently muted by the generally low energy of the beach environment, and the presence of sufficient time between storms in most years, with the exceptions of 1995, summer 1999-January 2000, and the period autumn 2004-autumn 2005, including Hurricane Frances.

2.5 Sensitivity to Sea Level Rise

Assessment of the sensitivity of a shoreline to erosion resulting from sea level rise involves consideration of several variables. Study of shorelines in the eastern United States by Gornitz (1993), Gornitz et al. (1991, 1993), and of Canada by Shaw et al. (1998) led to the identification of parameters which can be used to assess the sensitivity of a shoreline to erosion. Shaw et al. (1998) list seven critical parameters:

- relief,
- rock and/or sediment type exposed along the shore,
- landform type (e.g. cliff, beach, salt marsh),
- tendency of sea-level change (amount of rise or fall per 100 years),
- shoreline displacement (laterally, expressed in m / a);
- tidal range, and
- mean annual maximum significant wave height

Shaw et al. (1998) assigned each parameter an equal weight, and ranked variations within each from 1 (very low sensitivity) to 5 (very high sensitivity). By combining the scores for each parameter, sensitivity indices (SI) can be calculated as:

\[ SI = \sqrt{\text{product of scores of all 7 parameters} / 7} \]

Thus, a shore with the least sensitivity to coastal erosion would have a SI of \( \sqrt{1/7} \), or \(~0.38\), whereas the greatest value possible is \( \sqrt{5 \times 5 \times 5 \times 5 \times 5 \times 5 \times 5 / 7} \), or \(~108\).
Shaw et al. (1998) divided the coastline of Canada into three categories of SI. Coastlines with low sensitivity had SI values of $\leq 4.9$; moderately sensitive coastlines had values between 5.0 and 14.9; and highly sensitive coastlines had values in excess of 15.0. A single sensitivity index was calculated for all 2899 of the 1:50,000 map areas along the Canadian coastline.

Throughout the analysis, Shaw et al. (1998) carefully indicate that the regional nature of this investigation may serve to partially conceal local problem areas. Investigation on a regional scale (c.f. Catto et al., 2003; Daigle et al., 2006) allows further subdivision of parameters, assessment of their relative importance locally, and designation of more specific areas for categorization.

Shorelines with high relief above sea level are relatively insensitive to erosion. In contrast, shorelines with relief less than the mean significant wave height are susceptible to periodic inundation, increasing the potential for erosion. Offshore of eastern Newfoundland, the mean annual significant wave height is estimated at 7 m - 8 m (Neu 1982; see also Lewis and Moran, 1984), with the 10-year and 100-year values estimated at 11 m and 15 m respectively. These values can be compared with the recorded 15 m height at the offshore wave-rider buoy and 18 m inundation level associated with the January 2000 event. Estimates of significant wave heights based on modeling tend to underpredict extreme storm wave heights (Bacon and Carter, 1991; Cardone and Swail, 1995; Cardone et al., 1995), and wave heights in excess of 30 m have been recorded offshore of the south coast of Newfoundland during storm events (Swail, 1997).

In this study, shorelines with relief less than 7 m are considered to have a very high risk relief factor (5). Shorelines with relief less than 15 m are considered to have a high risk relief factor (4), and those with relief less than 20 m are assessed as moderate (3). Areas with relief of 30 m or less are assessed as having low risk (2), and those above 30 m are at very low or negligible risk (1).

The primary difference related to rock and sediment type along the coastline distinguishes areas with relatively resistant bedrock (such as Port aux Basques Harbour) from areas of coastal sand dunes (such as Grand Bay West and JT Cheeseman Provincial Park). The resistant granite of the Burgeo area has a very low risk factor (1). The schist surrounding Port aux Basques Harbour is less resistant to frost wedging, due to its
jointing and fracture pattern, but its sheltered position with respect to most storm tracks limits its exposure, reducing the sensitivity (2). In contrast, areas with exposed aeolian sand dunes flanking sandy beaches, open to the direction of prevailing winds, are very sensitive to erosion (with a sensitivity factor of 5).

Landform type also influences the sensitivity to coastal erosion. The steep fjord coastlines between Burgeo and Port aux Basques (1) and the rock platforms surrounding Port aux Basques Harbour (2) are less sensitive to erosion than are the dune-backed coastlines (4).

The tendency of sea-level change (amount of rise or fall per 100 years) also controls coastal erosion. The rankings of sensitivity indices for these factors follow those of Shaw et al. (1998). For Port aux Basques, sea level is currently rising at 3.3 mm/a, ca. 33 cm per 100 years. Coastlines with sea level rising between 21 and 40 cm/100a are assigned a sensitivity factor of 4 by Shaw et al. (1998).

Sensitivity factors for shoreline displacement vary from very low (1) for accreting shorelines, through low (2) for shorelines showing no net displacement, to very high (5) for shorelines receding at rates in excess of 1 m/a. Values throughout the study region for this parameter thus range from very high at Sanbands Provincial Park (rates > 1 m/a, Ingram 2004) to very low. At Port aux Basques Harbour, the bedrock shoreline has shown no perceptible change, and small gravel fringes have accumulated in some locations. The harbour is assigned a sensitivity factor of very low (1) for this parameter.

Tidal ranges in eastern Newfoundland lie within the microtidal and very lowest mesotidal limits. Port-aux-Basques Harbour has a mixed, mainly semi-diurnal tidal regime. The range during mean tide is 1.1 m, rising to 1.6 m during spring tide (Canadian Hydrographic Service, 2004 and 2005). Similar microtidal regimes were assigned a sensitivity factor of low (2) by Shaw et al. (1998).

The mean annual maximum significant wave height is also important in assessment of the sensitivity index. Along the eastern Newfoundland coastline, the significant wave height of 7 m - 8 m (Neu, 1982) establishes this parameter as having a very high sensitivity ranking.
By combining the values for all seven sensitivity factors, an overall coastal sensitivity index can be calculated. For Port aux Basques Harbour, the Coastal Sensitivity Index is:

\[ CSI = \sqrt{\frac{3 \times 2 \times 2 \times 4 \times 1 \times 2 \times 5}{7}} = 8.3 \]

This value lies in the lower range of the ‘moderate’ sensitivity classification. For Port aux Basques, the sensitivity factors relating to sea level history and wave activity are far higher than the geological and topographical factors. As all factors are equally weighted in the formula, the overall result suggests low-moderate sensitivity. Observations of the ineffectiveness of storm surges and waves on erosion of this coastline, however, suggest that the geological factors are locally dominant. Overall, Port aux Basques Harbour is not sensitive to coastal erosion.

For Sandbanks Provincial Park, the Coastal Sensitivity Index is:

\[ CSI = \sqrt{\frac{5 \times 5 \times 4 \times 4 \times 5 \times 2 \times 5}{7}} = 53.5 \]

This value indicates a coastline highly sensitive to erosion, which is in agreement with observations at the park.
2.7 Summary

- Sea level is currently rising at Port aux Basques at ca. 3.3 mm/a.
- Rising sea level will allow successive storm surges to rise higher and penetrate further inland.
- The coastline of southwestern Newfoundland has been subject to at least 5 storm surge events since January 2000. The largest of these was the storm surge of 21-22 January 2000.
- The estimated economic damage from the January 2000 event exceeded $1 million. However, study of other flooding events in Newfoundland indicates that actual costs were more than twice the reported figures in all instances. Applying a similar standard to Port aux Basques would suggest that the actual financial impact of the 21-22 January 2000 storm surge event would approach $3 million. This figure does not account for any losses resulting in disruption to transportation between Port aux Basques and the remainder of Newfoundland.
- The shoreline at Port aux Basques Harbour is not sensitive to coastal erosion resulting from sea level rise. Coastal erosion is occurring along dune-backed sandy shorelines, such as those at JT Cheeseman and Sandbanks Provincial Parks.
3. Analysis of Tidal and Storm Surge record at Port aux Basques Harbour

Dan Ingram, Brad DeYoung, Norm Catto, Evan Edinger

3.1 Introduction and Methodology

Port aux Basques is prone to frequent storm activity, particularly intense winds. Storm surges are commonly a consequence of such events. This chapter summarizes the investigations of the long term impacts on water level height, assessing the role of tidal variation on storm surge elevation. Detailed discussion is presented by Ingram and DeYoung (2005) and Ingram (2005). The aims of this investigation were:

- to determine whether the tidal regime is changing over time;
- to determine the astronomical variations effecting any changes;
- to relate any residual change in tidal regime to changes in sea level and/or wind or storm surge activity; and
- to assess the implications, particularly with respect to the impact on port and ferry operations.

Statistical analysis utilized tide and climate data obtained from the Marine Environmental Data Service (MEDS) of Fisheries and Oceans Canada, and Environment Canada, respectively. The tide data dates back to 1935 but contains many large gaps, particularly during the 1930s through to the 1950s. The set, however, is largely complete from 1959 to present, although gaps exist due to mechanical problems with the gauge. For the purposes of this study, records from the 1950s through to the end of April 2005 were analysed. Unfortunately, there is no climate data for the Port aux Basques station prior to 1966.

The tide and pressure data was analysed using MATLAB (Version 6.5.1.199709 Release 13) in conjunction with T_TIDE. These programs were accessed through a computer work station in the Department of Physics and Physical Oceanography at Memorial University. T_TIDE was obtained from Professor Rich Pawlowicz, Ocean Dynamics Laboratory, University of British Columbia (http://www2.ocgy.ubc.ca/~rich/).
3.2 Analysis

Initially, data was reconfigured for compatibility with MATLAB and T_TIDE. This included converting the dates to the Julian calendar and the times from Newfoundland Standard Time (NST) to Greenwich Mean Time (GMT). The data was placed in annual increments for analysis using T_TIDE. Classical tidal harmonic analysis (Godin, 1972) was completed on the raw, unaltered water level data. This separated the predicted harmonic tide from the actual recorded water level, and thus separated the tidal residual from the actual tide.

The dominant tidal constituents were identified from the predicted harmonic tide. The frequency, amplitude, and phase of each constituent were separated and listed in an ASCII file. Generally, 67 constituents were identified for each data set but the number varied depending on the completeness of the record for any particular year.

For this study, only the most significant constituents (those with an amplitude exceeding 0.0400 m) were investigated further. Eight such constituents were identified; \(S_2, M_2, N_2, K_1, O_1, K_2, SSA, \) and \(SA.\) The frequencies of each are listed below in Table 3.1.
Table 3.1: Tidal harmonic description, period, and frequency of selected tidal constituents (modified from LeBlond and Mysak, 1978).

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Tidal Harmonic Description</th>
<th>Period (semi-diurnal, diurnal, or longer)</th>
<th>Period (mean solar hours)</th>
<th>Frequency (cycles per hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2</td>
<td>Principal solar</td>
<td>Semi-diurnal</td>
<td>12.00</td>
<td>0.0833333</td>
</tr>
<tr>
<td>M2</td>
<td>Principal lunar</td>
<td>Semi-diurnal</td>
<td>12.42</td>
<td>0.0805114</td>
</tr>
<tr>
<td>N2</td>
<td>Longer lunar elliptic</td>
<td>Semi-diurnal</td>
<td>12.66</td>
<td>0.0789992</td>
</tr>
<tr>
<td>K2</td>
<td>Luni-solar declinational</td>
<td>Semi-diurnal</td>
<td>11.97</td>
<td>0.0835615</td>
</tr>
<tr>
<td>K1</td>
<td>Soli-lunar declinational</td>
<td>Diurnal</td>
<td>23.93</td>
<td>0.0417807</td>
</tr>
<tr>
<td>O1</td>
<td>Main lunar</td>
<td>Diurnal</td>
<td>25.82</td>
<td>0.0387307</td>
</tr>
<tr>
<td>SSA</td>
<td>Solar semi-annual</td>
<td>Longer period</td>
<td>4393.3 (182.6 days)</td>
<td>0.0002282</td>
</tr>
<tr>
<td>SA</td>
<td>Solar annual</td>
<td>Longer period</td>
<td>8767.6 (365.2 days)</td>
<td>0.0001141</td>
</tr>
</tbody>
</table>

An annual mean time series was plotted for the amplitude of each constituent. The most evident trends or cycles were shown by K1, N2, M2, O1, and S2.

Once the predicted harmonic tide and its constituents were identified and removed the raw residual water level data was analysed. It is this component that is of greatest interest since it includes the atmospheric pressure component, amongst other factors, and any associated storm surge events.

3.2.1 Residual Water Level

The residual, non-tidal data was zeroed by subtracting the mean from each data point. Each annual time series was then prepared for filtering in T_TIDE, to remove any non-tidal noise from the data. For filtering, each series had to be relatively complete,
generally with record gaps not exceeding one month. Years with large continuous gaps, or numerous smaller ones, were omitted for the purposes of filtering and further analysis. Filtering in MATLAB requires that any time series must be complete with no gaps, and therefore, any gaps in the record had to be infilled with data that was interpolated. This could be reasonably done with gaps less than one month in duration, but not with large or frequent ones. For the purposes of this analysis, simple linear interpolation was used. This did not fill the gaps with accurate water level data but rather simply filled the voids allowing a filter to pass over without complications, as filters do not respond well to discontinuity.

The Butterworth digital lowpass IIR filter (Etter, 1993) was used for each annual time series. Butterworth filters have maximally flat passbands and stopbands and are written as:

$$[B,A] = \text{butter}(N,Wn)$$

with $N$ representing the order of the filter and $Wn$ being the cutoff frequency normalized to the Nyquist frequency (Etter, 1993). For the filtering of the water level residual, an order of 6 ($N$) and a cutoff frequency of 0.03 cph, or roughly 33 hours, were used.

Although the filtered data removes other noise (such as instrumental error and high frequency variability), permitting a more accurate statistical assessment of trends, the raw water level residual is still utilised, particularly when dealing with storm and surge events since the main interest is with the actual water level in those situations. Therefore, the annual raw residual time series were used to determine annual maximum events and the length of time that water levels exceeded particular thresholds.

3.2.2 Extreme Water Level Events

Two water level thresholds were used. The most important threshold is a residual, or surge, that exceeds 60 cm. This is the widely recognised definition of a storm surge event (c.f. Murty, 1984; Forbes et al., 2004). Figure 3.1 shows the number of events that exceeded 60 cm each year and the number of hours exceeding this level.

The same data was also plotted using a threshold of 40 cm (Figure 3.2). This provides an indication of the trend of water level events greater than the mean. Although
there may be no evident trend for actual surge events (those exceeding 60 cm), there may be a large increase in higher water level events. Evident increases in high water levels may not be sufficiently extreme enough to be classified as surges. Utilising a lower arbitrary water level threshold in conjunction with the standard storm surge definition allows better assessment.

Years with a complete data set are identified by the solid blue bars, and those years with partial records are represented by the grey bars. Any years with significant gaps, particularly during the winter months, have been omitted and marked with an asterisk. A data set was considered complete (solid blue) if no gaps exceeding 24 hours were present in the record, meaning that the yearly data set must be at least 97.3% complete. The plots were excluded totally (marked by an asterisk) if the winter record was missing more than 30 days in total, or if the annual data set was missing more than a total of 90 days. Thus, the winter data set had to be more than 66.7% complete, and the overall yearly record had to be more than 75.3% complete. All other years were classified as having partial records (grey shading).
Figure 3.1: The number of storm surge events (water level exceeding 60 cm) (A) and the number of hours the water level exceeds 60 cm (B) by year in Port-aux-Basques (1959 – 2004). The blue bars indicate a complete data set (less than 1 day total gap). Grey bars indicate partial data sets (a total gap exceeding 1 day but less than 90 days annually and/or 30 days during the winter). Asterisks (*) indicate omitted data sets due to very large gaps (more than 90 days total and/or more than 30 days during the winter).
Figure 3.2: The number of water level events exceeding 40 cm (A) and the number of hours that the water level exceeds 40 cm (B) by year in Port-aux-Basques (1959 – 2004). The blue bars indicate a complete data set (less than 1 day total gap). Grey bars indicate partial data sets (a total gap exceeding 1 day but less than 90 days annually and/or 30 days during the winter). Asterisks (*) indicate omitted data sets due to very large gaps (more than 90 days total and/or more than a 30 days during the winter).
3.2.3 Climate Factors

Atmospheric pressure data was converted to a water height equivalent (in metres) for comparison with water level data. This allows an assessment as to how much, if any, of the water level fluctuation is pressure dependent.

Wind speeds were converted to m/s and was used to calculate the drag coefficient ($C_D$) using the methods of Large and Pond (1981). The drag coefficient was reduced to 10 m height and neutral atmospheric conditions ($C_{DN}$) (Large and Pond, 1981).

Once the $C_{DN}$ was defined, the zonal ($u$) and meridional ($v$) components of wind speed and the wind stress was resolved into its zonal ($\tau_x$) and meridional ($\tau_y$) components:

$$\tau_x = \rho_A \cdot C_{DN} \cdot u \left( u^2 + v^2 \right)^{1/2}$$
$$\tau_y = \rho_A \cdot C_{DN} \cdot v \left( u^2 + v^2 \right)^{1/2},$$

where $\rho_A$ is the density of air (approximately 1.26 kg/m$^3$).

Using the zonal and meridional components, the absolute mean wind stress ($\tau$) values could be calculated (in N·m$^{-2}$ or Pa) as:

$$|\tau| = (\tau_x^2 + \tau_y^2)^{1/2}.$$  

As an absolute value the wind stress was plotted as a time series for composition with the residual water level and atmospheric pressure data plots. For this study, only the absolute values were considered. If specific storm events and associated impacts were to be studied, it would be valuable to consider each directional component separately. This would be particularly true when investigating the relationship between any given wind direction and the recorded water level in Port aux Basques Harbour.

3.3 Interpretation

3.3.1 Tidal Cycles

The most obvious cyclic patterns are seen with the amplitudes of $M2$, $O1$, and $K1$, all of which display two clear oscillations with a period of about 18 years each (figure 3.3, 3.4. 3.5). These are thus likely the dominant components of the 18.6-year tidal cycle. A longer time series, however, would be required to make any definite interpretations.
Figure 3.3: Amplitude for tidal constituent M2 (1935 - 2005) based on analysis of hourly data from each year.
**Figure 3.4:** Amplitude for tidal constituent O1 (1935 - 2005) based on analysis of hourly data from each year.

**Figure 3.5:** Amplitude for tidal constituent K1 (1935 - 2005) based on analysis of hourly data from each year.
For each constituent, the 18-year cycle can be attributed to the previously identified tidal cycle, although the 2 separate 18-year oscillation sets are of different variance. A longer time series that illustrates more of the cycles would be required to make any interpretations. The same can be said for downward trend, as it cannot be accurately explained without a longer time series.

3.3.2 North Atlantic Oscillation

The cyclic pattern of the constituents, particularly $M2$ that has the dominant influence due to its relatively large amplitude, was also compared to the North Atlantic Oscillation (NAO; Hurrell et al., 2003).

The $M2$ and NAO display a similar cyclic pattern with similar periods (Figure 3.6). The time series are also plotted along with the annual maximum surge. The annual maximum surge bar plot has been colour coded on the basis of completeness of the record. Years with no significant record (1964 and 1979) have been omitted completely. To evaluate the relationship between M2 and the hours of exceedence of a 40 cm water level and the NAO, scatter plots were constructed (Figure 3.7). From these plots it is clear that there is no real correlation, although all three variables exhibit some cyclical pattern.
(A) M2 Amplitude

Year
Water Level (m)
0.41 0.42 0.43 0.44 0.45 0.46 0.47

(B) NAO Index

Year
NAO Index
-6 -4 -2 0 2 4 6

(C) Annual Maximum Surge

Year
Water Level (m)
0.2 0.4 0.6 0.8 1.0
Figure 3.6: Yearly comparison of the amplitude of tidal constituent M2 (A), the NAO Index (B), and annual maximum surge height (de-tided residual) (C). Complete data sets and those with gaps are shown in blue and grey, respectively.
(A) Annual Maximum Surge (m) vs. NAO Index

(B) Duration (Hours) vs. NAO Index
Figure 3.7: Scatter plots of the NAO Index versus the annual maximum surge height (A) and the number of hours per year that the water level exceeds 40 cm (B) (1959 – 2004). Note the lack of correlation between the two variables in each plot.
Scatter plots were also constructed comparing the NAO Index versus the number of events exceeding 40 cm and 60 cm and the number of hours that the water level exceeded 60 cm. No relationship was evident in either plot. Similarly, no relationship was present when the NAO was plotted against the annual maximum surge either. These results complement the work of Karn (2004) who indicated that the local significance of the NAO is very variable and no clear relationship or trend exists with respect to wind speed in Atlantic Canada.

3.3.3 Residual Water Level

The residual water level displays a very clear seasonal trend, as is evident when the monthly mean residual water level is plotted (Figure 3.8). The fall and winter months have a higher mean water level and a higher variance than do the spring and summer. This is expected as the stormiest months are during the fall and winter, which would cause increased surge activity and generally higher water levels. Based on mean seasonal data (1959-2005), the ratio of the standard deviations of the mean winter (January, February, March) and summer (July, August, September) water level is approximately 1.6, a considerable difference.
Figure 3.8 Monthly mean water level (de-tided residual) and variance from 1959 – 2005

There is a clear seasonality shown by the data, with higher water levels in the fall and winter months (Figure 3.8). Therefore, the plot displaying the mean annual water level (Figure 3.9) should be used primarily to further emphasize the large variability in the water level, as well as the challenges of working with an incomplete, very fragmented data set.
3.3.4 Influence of Atmospheric Pressure and Wind on Water Level

Residual water level is greatly influenced by atmospheric pressure and local wind, amongst other less significant factors. For Port aux Basques, its location with respect to northerly and north-easterly tracking low pressure systems and their associated winds provide many examples of this interaction.

Every storm and associated surge is unique. There is no one template or set of guidelines outlining how a particular system will impact any given area. There is, however, some strong relationships that exist between water levels and atmospheric pressure and wind (Table 3.2). Atmospheric pressure, similarly to water level, shows

Figure 3.9: Monthly mean atmospheric pressure (height equivalent in metres) and variance from 1959 – 2005.
obvious seasonality. The mean monthly pressure, plotted as height equivalent, is basically the inverse of the water data for the same period (1959-2005).

Table 3.2. Recorded and calculated data for selected storm events.

<table>
<thead>
<tr>
<th>Recorded / Calculated Variable</th>
<th>JAN 2000</th>
<th>OCT 1974</th>
<th>FEB 1969</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water Level</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum actual (m)</td>
<td>nd</td>
<td>2.15</td>
<td>2.54</td>
</tr>
<tr>
<td>Maximum residual (m)</td>
<td>nd</td>
<td>0.51335</td>
<td>0.82421</td>
</tr>
<tr>
<td>High tide prediction (m)</td>
<td>0.53636</td>
<td>0.49543</td>
<td>0.49543</td>
</tr>
<tr>
<td><strong>Atmospheric Pressure</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum recorded value (kPa)</td>
<td>96.98</td>
<td>97.73</td>
<td>98.24</td>
</tr>
<tr>
<td>Minimum height equivalent (m)</td>
<td>-0.41787</td>
<td>-0.34918</td>
<td>-0.3044</td>
</tr>
<tr>
<td>Proportion of surge due to pressure (%)</td>
<td>nd</td>
<td>68%</td>
<td>40%</td>
</tr>
<tr>
<td><strong>Wind</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum speed (km/h)</td>
<td>96</td>
<td>84</td>
<td>93</td>
</tr>
<tr>
<td>Direction (deg)</td>
<td>180</td>
<td>170</td>
<td>110</td>
</tr>
<tr>
<td>Direction (descriptor)</td>
<td>S</td>
<td>S</td>
<td>E</td>
</tr>
<tr>
<td>Max stress (Pa)</td>
<td>1.9842</td>
<td>0.87116</td>
<td>1.1858</td>
</tr>
</tbody>
</table>

Seasonal sea-level rise is illustrated in the monthly mean water level, or is at least an active factor, amongst others such as wind stress. The opposite is true during the summer months. The variance is much less and the mean is much smaller. The obvious seasonal difference in variance, for both the water level and atmospheric pressure, is likely due primarily to the climatic regime. Port aux Basques is prone to fall and winter storms and such isolated events will create anomalies in the data and thus increases the variance. Conversely, the summer months are relatively calm and the isolated storms are typically less severe resulting in less variability in the data.

The influence of atmospheric pressure is evident for specific storm events as well. A relationship clearly exists as the water level and wind peak at relatively the same time as the pressure dips to a minimum. This example displays a somewhat idealistic representation of the relationship. Other factors, such as wind direction and lag times attributed to low pressure system movement, are also involved. In this example, the maximum surge of 0.824 m peaked at approximately 1530 hrs GMT on 4 February. This practically coincided with the high tide, producing a combined water level of 2.54 m above chart datum. This is the ‘worse case scenario’ with respect to destructive impacts for storm surges. If the maximum surge occurred during low tide the actual water level would be much less since the water level resulting from the harmonic tide would not be
factored in. When a high tide and surge coincide there is essentially a stacking effect and
the already elevated water level, as a result of the high tide, is further elevated due to the
surge. The impact is enhanced even further in the event that the high tide is the higher of
the two of the daily cycle and/or it occurs during spring tide conditions.

High winds were prevalent for about 24 hours during the 4 February storm, both
preceding and following the maximum surge. The peak sustained winds (93 km/h) were
logged at 0530 hrs GMT and exhibited a stress of about 1.19 Pa. These winds subsided
for some time later that day but returned again to reach a maximum of 89 km/h (a wind
stress of 0.93 Pa) at 1230 hrs GMT. Thus, the maximum surge lagged the peak winds by
about 3 hours. At this time the stress was gauged to be about 0.93 Pa. Peak winds,
however, primarily serve as a gauge of maximum intensity and the duration of significant
winds must be noted as well. Often the winds have weakened by the time of the surge maximum but the sea state still demonstrates the effects of the previously intense winds. As a result, it cannot be assumed that wind stress does not have a significant impact simply due to a decrease in velocity at the time of the surge. Similarly to the impact of atmospheric pressure, the effects on the water level often lag in time. The ocean does not react instantaneously to changes in environmental or meteorological influences. It takes time to adjust and thus water level values commonly, but not always, lag wind and pressure changes.

3.3.5 Extreme Water Level Events

Extreme water level events are relatively common in Port aux Basques. During the partially complete water level record, there were a total of 69 surge events (residual water level greater than 60 cm) that persisted for approximately 230 hours over the 45 year period (1959 – 2004), an average of 1.5 events and 5.2 hours of surge conditions annually. This estimate is less than the actual number, as many events were not logged due to the very fragmented record. However, the extreme water level record for Port-aux-Basques displays an oscillating pattern. Some years with a complete data record indicate no extreme events, while others with only a limited number of water level records show a large number.

3.4 Recommendations and Suggestions for Future Work

The methods and techniques used for this research were very applicable and proved to be effective, but the data set was a limiting factor. With a relatively short and fragmented data set, long term trends could often not be identified. This was particularly true for changes with respect to storm surge frequency; either exceeding the 40 cm or 60 cm threshold, and maximum storm surge height. It was clear, however, that storm surges are very variable over the duration of the data.

To make a better assessment of the long term trends, a long time series would have to be analysed. Unfortunately, the tide gauge in Port-aux-Basques was not installed.
until 1935 and the record is largely incomplete until 1959 and contains large gaps for the
duration of the record. Therefore, this project can possibly serve as the starting point, or
base-line, for continuing research as more data is collected at Port-aux-Basques. Ideally,
the time-series would be expanded at the end of each year. This, however, will mean that
an obvious trend cannot be established for many more years. The outcome is unknown,
especially as there are predictions that climate change is accelerating and its impacts will
likely be more apparent.

Another option would be to reconstruct the past record. This would involve
significantly more statistical analysis, but is possible. Any such re-construction would be
based on tide gauge records from other Atlantic Canada locations that were operational at
the time. The recent water level data from Port-aux-Basques would first be compared to
the data from other stations. Once a correlation is established the past gaps in the record
would be able to be roughly interpolated. If the other gauge records pre-date 1935, the
records preceding the first Port-aux-Basques data could be interpolated as well. Such
interpolations would not be perfectly accurate for event- or storm-specific water levels,
but could be used to determine the frequency and approximate magnitude of surges.
Thus, it will enable the input of more data to better establish a trend. Actual water levels
could not be determined due to the large local-variability in Atlantic Canada. The same
storm system often has a very different impact in different locations, even if they are
geo graphically close.

Future research could also be enhanced by upgrading the tidal network. The
gauges should be maintained in a manner that large gaps are not present and any gaps are
not as frequent in the record. This is especially true for the winter months when storms
are more prevalent and having a record of the water level is more critical. Essentially, the
present state of the Atlantic Canadian tide gauge network is not acceptable for scientific
research nor for public safety. This can be exemplified very clearly during the very
intense and destructive storm of January 2000. During this severe storm the gauge was
not operational, had not been for 130 days prior to the surge (since 14 September 1999)
and did not log data for another 38 days after. The total non-operational period for this
gap was 168 days, and many other gaps in the record exceed this. Notably, at least 3
other intense storms (wind stress > 1.5 Pa) impacted the area during this period, and these
water levels were not logged. The networks require adequate maintenance and associated funding, in order for significant and productive research to continue and for public safety.

3.4 Summary

- There is no clear net change in tidal regime for the period of tidal records for Port aux Basques (1935-present). There is, however, an indication of the de-tided residual increasing over time (approximately 10 cm over the 46-year record; 1959 to 2005). Unfortunately, this increase cannot be accurately interpreted since the data set is highly fragmented, but some of the increasing trend is likely due to relative sea level rise in the area.
- There is a clear seasonal trend in mean water level. The mean and variance is higher during the fall and winter than in the spring and summer.
- The atmospheric pressure exhibits a clear seasonal trend. The pressure is lower with a higher variability during the late fall and winter.
- There is no obvious correlation between the NAO and the tidal constituents, such as M2, or storm surge activity (neither by frequency in terms of number of events or duration nor by maximum surge height).
- The annual number of events that exceed 60 cm shows no real trend and there has been little change in the annual maximum storm surge elevation.
- The maximum water level for extreme events, such as the January 2000 storm, that have been excluded from the data record can be roughly estimated using basic statistical correlations based on the recorded meteorological conditions along with the records of other previous storm/surge events.
- Tidal gauge networks require adequate maintenance and associated funding, in order for significant and productive research to continue and for public safety.
4. Records and Physical Impact of Wreckhouse Events

Norm Catto, Jennifer Straatman, Dale Foote, Dermot Kearney

4.1 Previous Research

Wreckhouse Events have impacted surface transportation through southern Newfoundland since the construction of the Newfoundland Railway, and numerous anecdotes exist (Morris, 1977; Harding, 1992; Lingard, 1997). Studies and archival documentation concerning these events, however, are surprisingly limited. Four previous studies have considered the impacts on transportation and hydroelectric transmission in the area.

Sutherland et al. (1963) investigated extreme wind events and train delays in the Wreckhouse-St. Andrews area for the period 1956-1962, at the request of Canadian National Railways. The wind data used in the study was from the weather station observations at St. Andrew’s, which the authors related to weather conditions at Wreckhouse. The meteorological component of the study incorporated the conclusions of earlier research by Janz, using data obtained between 1948 to 1958. Further discussion of the relationship between conditions at Wreckhouse and wind data from surrounding stations is presented in chapter 5 of this report.

The majority of the events occurred with southeasterly winds ahead of warm fronts or trowels, and could develop quickly. The phenomenon was a result of the cold air becoming trapped between the advancing warm front and the high terrain a few miles inland. With continued pressure from the warm air, the cold air was forced through the natural funnel at much greater than normal velocity. It was proposed that a mechanism similar to the Bernoulli affect could be the cause of the strong winds.

The majority of the abnormal winds originated from the east or southeast, ahead of warm fronts, and diminished rapidly with the passage of the front. They occurred predominately from the late fall to early spring with few or no events during the summer.

Wind speeds increased very rapidly over short periods of time, reaching 144 km/h (90 mph) with gusts to 190 km/h (120 mph). A total of 130 gale force events were documented between 1956 and 1962, of which 84% originated from the east or southeast. These winds were responsible for the delays in rail traffic.
Sutherland et al. (1963) stated that the abnormal winds producing Wreckhouse Events were assisted by funneling along the flanks of the Red Rock Hills, Sugar Loaf Hill and Table Mountain. The presence of the Horizontal Wave Forest at Red Rock Hills was associated with the wind regime. The climatology of Wreckhouse events is discussed further in chapter 5 of this report.

Sutherland et al. (1963) were primarily concerned with delays to rail traffic (Tables 4.1, 4.2, 4.3). Days with wind speeds in excess of 65 km/h (40 mph) were compared with traffic delay data obtained from the office of the Superintendent of the Line of the CNR. Train delays occurred on 44 days with gale force (or stronger) winds recorded at St. Andrew’s, and on 13 days with lower wind speeds. All of the train delays occurred when the wind was from the east, southeast, or south. Most of the gales occurred during the months of November through March. Over the 8 year period, the 57 delays represent an average of 7.1 per year.

As traffic was delayed on approximately 33% of the number of days with gale force or stronger winds, Sutherland et al. (1963) also looked at the number of consecutive hours the winds were strong, hypothesizing that perhaps the strong winds did not last very long, and therefore did not conflict with the train schedule. They concluded that there was insufficient data to explain why train delays only occurred on some of the days with strong winds, but not others, and why delays sometimes occurred when the winds were not as strong (i.e. less than 65 km/h). The longest train delay was 19.5 hours, the shortest 1.5 hours.

Table 4.1 Number of train delays by month and year in the Wreckhouse area, 1956 to 1962

<table>
<thead>
<tr>
<th>Year</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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<tr>
<td>1956</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>1957</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<td>1</td>
<td>1</td>
<td>9</td>
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<td>1959</td>
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<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>2</td>
<td>0</td>
<td>7</td>
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<td>1960</td>
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<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>9</td>
</tr>
<tr>
<td>1961</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
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<tr>
<td>1962</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>12</td>
<td>7</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>11</td>
<td>8</td>
<td>56</td>
</tr>
</tbody>
</table>
Table 4.2  Days of strong winds in relation to the number of train delays 1956 to 1962

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days of strong winds</td>
<td>23</td>
<td>16</td>
<td>15</td>
<td>10</td>
<td>9</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>9</td>
<td>18</td>
<td>23</td>
<td>130</td>
</tr>
<tr>
<td>Days of delays with winds over 40 MPH</td>
<td>6</td>
<td>9</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>8</td>
<td>44</td>
</tr>
<tr>
<td>Days of delays with winds under 40 MPH</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 4.3  Trains delays in comparison with wind direction 1956 to 1962

<table>
<thead>
<tr>
<th>Wind Direction</th>
<th>N</th>
<th>NE</th>
<th>E</th>
<th>SE</th>
<th>S</th>
<th>SW</th>
<th>W</th>
<th>NW</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days of strong winds</td>
<td>0</td>
<td>0</td>
<td>27</td>
<td>82</td>
<td>9</td>
<td>7</td>
<td>2</td>
<td>3</td>
<td>130</td>
</tr>
<tr>
<td>Days of delays with winds 40 MPH or over</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>27</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>46</td>
</tr>
<tr>
<td>Days of delays with winds less than 40 MPH</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>7</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>13</td>
</tr>
</tbody>
</table>

Weather Engineering Corporation of Canada (1982) examined the cause of the extremely high winds at St. Andrew’s and elsewhere in the Codroy Valley that damaged Newfoundland and Labrador Hydro transmission towers along TL-214, with a goal of assessing design and maintenance. Using the data obtained from the St. Andrew’s weather station for the period 1953-1966, the frequency distribution and extreme values of the wind speed were determined as well as return periods of extreme wind events and the probability of occurrence of any wind speed.

Rawinsonde data from Argentia, obtained during severe storms, was used to calculate wind speed frequency distributions for 305 m (1000 ft) elevation and compared with the surface observations at St. Andrew’s. The results indicated the wind speeds at St. Andrew’s were stronger at a given return period than were winds 305 m above the ground, in contrast to normal conditions elsewhere.

This study downplayed the role of funneling or channeling of the winds through gaps in the high terrain as the cause of the extreme winds. Using wind data from other recording equipment, the study indicated areas of divergent flow off the Long Range Mountains were also regions of severe winds. It was proposed these winds were a type of
fall-wind caused by the rapid downslope flow off the Long Range Mountains. When east or southeast winds off the interior plateau of the Long Range Mountains reached the escarpment, would drop-off quickly to the low lying areas at Wreckhouse and St. Andrews. Local channeling of the wind through river valleys modified the winds but it was essentially a downslope wind phenomena. The study investigated the relationship between downslope wind storms in the Codroy Valley and the energy of the air stream. Theoretical relationships were applied for two storms and the results correlated well with observed winds and damage to transmission lines in the Codroy Valley. The study also investigated the extreme gustiness of the downslope winds and concluded the Boyd gust formula fitted the observations at St. Andrew’s to a good approximation.

The primary objective of this study was to assess the design of Transmission Line 214. Consideration of the data indicated that TL 214 should be designed to withstand an extreme sustained wind speed of 177 km/h, with gusts to 235 km/h.

TRO Engineering (2002) conducted a further assessment of TL-214 for Newfoundland and Labrador Hydro. Based primarily on the Weather Engineering Corporation (1982) report, it was recommended that TL-214 be redesigned to withstand gusts to 235 km/h, rather than the original design standard of 177 km/h for individual gusts. TRO (2002) conducted a design analysis based on the higher gust value, focusing on phase spacing, horizontal insulator swing, and conductor design. A central concern was ensuring that conductors had sufficient weight so that they would not be displaced by strong winds towards the cross-arms, as contact between the two would result in design failure.

ADI Limited (1994) conducted a study of Wreckhouse winds and their effect on truck traffic, to assess the cost effectiveness of a wind warning system. Warning signs and markers have subsequently been installed along the highway. The intent of this study was to assess the magnitude of accidents and delays, and to discuss remedial measures, rather than to analyze the meteorological situation.

Over the five year period 1989-1993, ADI Limited (1994) documented 17 rollover/high wind blowoff accidents. Of these, only 9 (59%) occurred during the winter months of November through March, suggesting that high winds are possible during any season. The estimated average cost of each accident, based on insurance claims for
vehicles and cargo, was ca. $50,000 in 1993 (estimated by AJ Bell and Grant Ltd., Insurance Brokers, Halifax), equivalent to ca. $70,000 in 2006. The mean annual cost estimate from 1989-1993 was $170,000, equivalent to $236,000 in 2006. These figures do not include uninsured losses, and also refer only to the value of the hardware involved.

The cost of delays was also estimated by ADI Limited (1994). At Doyles, high winds force westbound truckers to remain parked until the winds subside. The estimate of 25 such events per year, each one lasting approximately 6 hours, affecting approximately 100 trucks per event, produces a value of 15,000 truckers hours per year lost in delays in each direction, for a total of 30,000 hours lost in delays per year. With adjustment for inflation between 1993 and 2006, the total estimated loss by truck traffic delay each year is ca. $1.9 million. This figure does not include delays to smaller, non-commercial vehicles, or costs involved with response to accidents or road maintenance and repair.

4.2 Archival Research – Western Star

The previous studies involved relatively short investigations of specific forms of transportation and infrastructure. Although estimates for highway traffic delays for the period 1989-1993 are broadly valid for 2006, given the meteorological data available (see Chapter 5) and the similarity in driving practices and vehicle design, comparison of rail and road delays would not produce a valid estimate of the amount of change resulting from changed climatic factors. Consequently, efforts were made to investigate archival sources, in an attempt to determine if accident and delay frequencies had changed throughout the period of railroad operation. Any such changes could then be considered in light of changes in railroad equipment and maintenance protocols.

The Western Star newspaper (based in Corner Brook) was the most constant source of data concerning derailments and delays. Publication of the Western Star started in April 1900, and has continued until the present. Due to time constraints, and the lack of detailed archival cataloguing of the newspaper, it was decided to investigate three sample periods of two years each. This involved studying all of the issues from 1901-1902, 1931-1932, and 1951-1952. All references to train delays due to any climate or weather-related cause for the line between Stephenville and port aux Basques were noted.
These dates were chosen because they avoided the World Wars (1914-1918, 1939-1945) which would have limited the type of information published in a newspaper. The earlier volumes of the paper had a reasonable account of such local information, but later volumes, particularly those from the 1950s, had expanded to include more international news, advertisements, and current clothing fashions, at the expense of local news.

The data from 1901-1902 indicated a total of 9 recorded delays. This figure represents the lowest possible estimate, as only the most extensive delays would be considered newsworthy. The most significant event occurred on 25-27 November 1901, and involved storm surge damage as well as high winds:

Friday 29 November 1901 Vol. 2 No. 62 [p. 3] “TERRIFIC GALE Held up Express Train AT CODROY! Monday’s express to connect with the S.S. Glencoe was held up at Little River station all night. A terrific gale swept through the Codroy valley and carried the waters of the ponds in clouds of spray for hundreds of yards. It seemed as though rain was descending in torrents whereas really the night was comparatively clear. It was hardly safe to be moving from car to car on the train, the force of the wind being so great as to almost lift a man off his feet. In view of last year’s accidents, in which one train was blown from the track and burnt up and another entirely derailed, the railway people are acting prudently in stalling the trains during such peculiar weather conditions …”

[p. 4] “TIDAL WAVE Visits West Coast. Great Damage to Railway. Not for seventeen years has the West Coast been visited by such a tide as that experienced on Wednesday forenoon. Fortunately the day was calm and there was no swell on, otherwise stores and dwellings would have been floating about … at Grand Bay, or, to be more accurate, at Barachois, about five miles east of Port au Basques, the terminus of the railway, the wind blew with great force and the trestle work and gravel bed succumbed to the ceaseless lashing of the waves. The ballast was washed from under the ties and piles for nearly a hundred yards and all traffic became suspended. The
express for St. John’s with the *Glencoe*’s mails and passengers was stalled at Port au Basques and did not leave until 5 o’clock yesterday afternoon, reaching here shortly after four o’clock this morning.

“The express from St. John’s to connect with the *Glencoe* was held up at Little River Wednesday night and was unable to reach P.A.B. The passengers and mails were transferred to a train on the opposite side of the washout and conveyed to Port au Basques, where they arrived at 5 p.m. yesterday. The *Glencoe* left an hour or two later for North Sydney.”

In contrast, study of the issues from 1931 and 1932 produced no references to storm activity or related delays. One article did comment upon heavy winds and snow at Port aux Basques, but specifically mentioned that this did not affect the train schedules.

Study of the 1951-1952 issues revealed discussion of three storms sufficient to cause damage and delay to railway traffic. The 29 June 1951 issue (p. 5) also reported that,

“Two Men Badly Injured When Gale Blows Truck Over On The Highway.
St. Andrews – (Special) – An accident occurred on the Trans-Canada Highway last Sunday when a truck turned over and two men were badly injured. It is reported that the truck blew over during a severe southeast gale which raged over the Valley that day. This is the first accident to occur on the new highway.”

The low totals for delays recorded in the *Western Star* for these sample years (between 0 and 4.5 per year for the three time periods) contrast with the annual average of 7.1 delays per year noted by Sutherland *et al.* (1963). Improvements in engine design, weather forecasting, and track maintenance would be expected to result in decreasing total delays over time, under a regime of consistent climate. However, the low totals more likely reflect a lack of reporting of incidents in the *Western Star*, rather than an actual increase in the number of delays. Comparison of the 3 delays reported over the 1951-1952 period in the *Western Star* with the 7.1 yearly average noted between 1956
and 1962 suggests that under-reporting is more likely than a rapid increase in gale frequency.

4.3 Canadian National Archives

Delays to rail traffic should primarily be recorded by the operators. Consequently, inquiries were made to locate the CN archival material relevant to the Newfoundland Railway, although previous efforts in this regard in conjunction with other studies (e.g. Catto and Hickman, 2004; Catto, 2006b) had proven unsuccessful.

The CN archives are part of the Library and Archives Canada collection in Ottawa (Record Group 30). The available records appear to consist of the Newfoundland Railway Records for 1881, 1884, and 1904-1946, specifically including:

1) income and expenditure graph 1904-1946
2) tariffs and pay book 1915-1949
3) photographs and time table 1928

Initial investigation, facilitated by Library and Archives Canada staff, revealed no material pertinent to delays of traffic, or to repairs of the line. The available records concerned primarily tariffs, timetables, price books of supplies, and bills paid. Further research would entail diligent analysis of all the materials, but the preliminary investigations suggest that no archival materials pertaining to delays in traffic have been maintained.

4.4 Other Archival Research

On advice from Library and Archives Canada, the Merrilees Transportation Collection website, part of the Library and Archives Canada website (http://www.collectionscanada.ca/trains/h30-6000-e.htm) was consulted, but yielded no useful information. Further research in the archives of the Canadian Railroad Historical Association, assisted by Josee Vallarand, archivist; the Provincial Archives of Newfoundland and Labrador (including the Reid Collection); the Railway Coastal Museum (of NL), assisted by Pam Correstine, former archivist; the AC Hunter Library; and the City of St. John’s archives also proved unsuccessful.
Search at the Provincial Archives of Newfoundland and Labrador revealed a single item of potential interest. File 321 “Reid Nfld Railway, Statements, 1902-1919”, in addition to containing general statements of expenses such as maintenance of the entire railway line, also contains a chart entitled “Data – Reid Newfoundland Railway” which lists the miles of track, tons of freight carried, passengers carried, tie renewals, and other data for 1902 to 1919. It also lists train derailments, for the entire line, between 1904 and 1919. Derailment totals varied from 13 (1908) to 94 (1918). Neither the chart nor anything else in the file specifies the cause of the train derailments. The high totals, however, do suggest that train derailments were common occurrences, and thus perhaps were not comprehensively reported in newspapers at the time.

4.5 Summary

- At present, it is not possible to assess if any change has occurred in the frequency of Wreckhouse Events, as judged from resultant delays to transportation, over the historical record. The available archival data appears to be inadequate for such an assessment.
- Recent events, documented by meteorological data, are discussed in Chapter 5. Historically, Wreckhouse Events have been known and respected since the initial railway construction period.
- The most recent cost estimates of disruption to highway traffic, summarized by ADI Limited (1994), suggest that accidents cost ca. $236,000 annually, and delays cost a further $1.9 million (as measured in 2006 dollars). Thus, the cost of Wreckhouse Events to the provincial economy is in excess of $2.1 million annually.
- This figure only includes insured losses and delays, and does not include delays or damage to smaller, non-commercial vehicles, or costs involved with response to accidents or road maintenance and repair.
5. Climate and Meteorological Analyses

Dale Foote and Dermot Kearney

5. 1. Introduction

Southwestern Newfoundland and the Cabot Strait are vital to maintaining a link between the Island of Newfoundland and the rest of Canada. It is important that regular ferry service into the harbour at Port aux Basques and traffic movement via the Trans-Canada Highway be maintained. Highway traffic is often disrupted in the Wreckhouse area due to severe localized winds and ferry traffic due to high winds and rough seas in the Cabot Strait.

An analysis of the region’s wind and wave climatology over the past 35 to 50 years has been used to determine if there are any significant changes in wind velocity, duration and frequency and wave height. Several data sources were exploited:

1. Environment Canada’s National Meteorological Data Archives.
2. The AES40 North Atlantic Wind and Wave Climatology.
3. Environment Canada’s 100 Year (1901 - 2000) Tropical Cyclone Climatology for cities.

The southwest coast of Newfoundland and the adjacent waters of the Cabot Strait are located near the primary storm tracks of North America. Storms track south or southeast of the Cabot Strait or to the west or northwest through the Gulf of St. Lawrence toward Labrador or the Labrador Sea. Frequent and intense storm activity is often associated with low pressure systems approaching the Cabot Strait from the south. This is primarily due to the proximity of the North American landmass to the warm waters of the Gulf Stream. When cold air originating over the continental landmass, clashes with warmer moist air over the Gulf Stream, frequent cyclogenesis occurs. This makes the Gulf Stream off the eastern seaboard of the United States the most active area for cyclogenesis in the North Atlantic. When these storms move northeastward toward Atlantic Canada they can rapidly intensify in a favourable oceanic environment.
The interaction of these weather systems with the high terrain over southwestern Newfoundland can cause complex wind patterns, prevailing wind at Port aux Basques to be easterly, which is opposite to that of most places in North America, and severe downslope wind storms observed at Wreckhouse and St. Andrew’s.

Downslope wind storms are observed on the lee side of major mountain ranges such as the Canadian Rockies and the European Alps. These storms also occur on much smaller geographical scales as observed at Wreckhouse in southwestern Newfoundland and les Suetes winds at Cheticamp on Cape Breton Island (Desjardins, 1995). They occur when stably stratified air is forced to rise over a topographic barrier causing oscillations or disturbances in the mean flow. Depending on the height and shape of the terrain as well as the vertical wind and temperature structure of the lower atmosphere, different wind regimes can result including the Wreckhouse and les Suetes winds. During these events air is forced over a topographical barrier and upon reaching a supercritical flow (Froude number >1), will accelerate on the lee side of the barrier. As the disturbance descends and accelerates intense winds can be concentrated at the ground, analogous to a hydraulic jump, after which the flow begins to adjust back to a subcritical flow (Froude number <1). Results of numerical model simulations on the les Suetes in Cape Breton indicate a hydraulic analogy is applicable to describing that wind phenomena. Simulations of the Wreckhouse wind events would likely give a similar result.

In addition to the baroclinic synoptic scale storms that develop in the mid latitudes and move through the study area, the Atlantic tropical weather season between June and November, and the associated tropical storms and hurricanes, may affect the Cabot Strait region. Most of these storms weaken as they move northward and enter cooler waters and some transition into an extra-tropical low or post-tropical system.

Whether storms originate in the mid latitudes or tropical areas of the Atlantic Ocean, the Cabot Strait region is prone to frequent storms with high winds, heavy precipitation, large waves and storm surges.
5.2. Data Sources

5.2.1 Environment Canada’s National Meteorological Data Archive

Environment Canada (EC) maintains the archive of meteorological data in Canada and this study uses data from several sites contained in the archive: Port aux Basques (WZB), Burgeo (WBF), Stephenville (YJT), Sydney (YQY), Wreckhouse (XWR) and St. Andrew’s. Observation site history discussions are given below.

Figure 5.1. Map showing the locations of wind measurement stations used in the Southwest Newfoundland Cabot Strait Transportation Study.

The weather observations taken at Port aux Basques have a long and dynamic history. The earliest reports date back to 1929 when the observations were taken at the old Telegraph and Cable office. They were taken twice daily from an anemometer on top of a 150 foot cliff on a 20 foot tower. There were some meteorological inspector reports from the early 1930s but it appears the location of the observations remained at the telegraph office. No inspector’s reports were found for most of the 1930s and all of the 1940s. In 1955 the station was moved to the Loran transmitting station approximately 1.5
miles southwest of the Canadian National Railway station in Port aux Basques. From 1955 until June 1966 there were no wind measurements taken in Port aux Basques. In June of 1966 the U2A anemometer at St. Andrew’s was relocated to Port aux Basques on a hill 56 feet ASL and placed on a 43 ft high tower. The hill sloped away to the ocean in all directions except north and northeast where the terrain gradually rose to 200 feet ASL approximately three quarters of a mile away. There were no changes to the observation location until August 1983 when it was moved, 800 ft to the north northeast, to its current location. On this site the anemometer was 32 metres higher on the hill and placed on a 10 meter tower.

Meteorological observations at the Stephenville Airport began in January 1953 when the American military operated the facility as Harmon Field. From 1953 to June 1966 there were no inspector’s reports available. The Americans operated two wind monitoring systems located at each end of the 10,000 foot runway 09-27. In 1966 the Department of Transport managed the airport and a new anemometer was temporary installed on a 6 metre tower until later in the year, likely September (MSC Meteorological Inspector Brian Hulan, personal communication). The anemometer remains at the same location today.

Meteorological observations in Burgeo began in the summer of 1966 and continue today at the original location. The height of the anemometer has remained constant at 10 metres however in the summer of 1969 the type was changed from a 45B to a U2A. The anemometer rests on a 10 metre tower on small hill 75 ft above MSL which is 40 feet above station elevation. The site is well exposed in all directions.

Sydney Airport, as with Port aux Basques and Stephenville, has an inconsistent anemometer height and location history (see Karn, 2004). From June 1950 to August 1968 the anemometer location and height were changed several times. On August 31, 1968 the wind observations began at the present location and height.

Wreckhouse, located northwest of Port aux Basques in the Codroy Valley, is an open and barren stretch of land where trains were once blown off their tracks by severe local windstorms. Now it is usually large transport trucks that fall victim to these powerful winds (see Chapter 4). The place name Wreckhouse has thus become synonymous with the Wreckhouse wind phenomena.
The meteorological observations, taken at Wreckhouse, have been consistent in location and height since January 2000. Between 1953 and 1966 the observations were taken at St. Andrew’s and in the 1980s and early 1990’s at the nearby Starlight Lounge. These sites are in different areas of the Codroy Valley and also experience the Wreckhouse Effect.

5.2.2 AES40 North Atlantic Wind and Wave Climatology

The AES40 data set was developed at Oceanweather a specialized consulting firm serving the coastal and ocean engineering communities with support from the Climate Research Branch of Environment Canada. The hindcast involved the kinematic reanalysis of all significant tropical and extra-tropical storms in the North Atlantic for the period 1954-2003. This data set has the advantage of being consistent in its temporal and spatial resolution and with the height of its predicted wind. There was no need for homogenization of the data and changes in the wind climatology will be attributable to the forecast climatology.

5.2.3 Environment Canada 100 Year (1901 - 2000) Tropical Cyclone Climatology for Cities

Environment Canada has analyzed 100 years of tropical cyclone tracks through Atlantic Canada and recorded when these storms pass within 260 kilometres of 33 different locations. It was determined in 1986 by Barks and Richards of EC Atlantic that tropical cyclones coming within 260 km of a location have a high probability of producing gale force winds at that location.

We have decided to use the criteria of a tropical cyclone passing within 260 kilometres of Sydney or Port aux Basques to indicate when a tropical cyclone had the greatest probability of impacting travel through the Cabot Strait or southwestern Newfoundland.
Figure 5.2  Winter Storm Tracks
(A) Great Lakes Lows
(B) Cape Hatteras/Cape Cod Lows
(C) Gulf of Mexico Lows

Figure 5.3  Wind speeds and directions, Burgeo
No observations were missing.
Wind flow is FROM the directions shown.
Rings drawn at 5% intervals.
Calms included at center.

Figure 5.4 Wind speeds and directions, Port aux Basques

Figure 5.5 Wind speeds and directions, Stephenville
5.3 Analysis

5.3.1 Inhomogeneous data

Inhomogeneous data is the result of an inconsistent measurement history, i.e. changes in location, measurement technique or instrumentation. As documented in the site histories section some data used for this report has such inconsistencies. Two methods of correcting for non homogenous data were considered for this report.

1. Using the ratio of monthly averages before and after a modification in the sampling methodology to develop a correction factor to apply to one portion of the data. This method works well when only one variable changes. When there are changes occurring in climatological and sampling methods at the same time it is difficult to quantify what percent of change is due to instrumentation.
2. Correction of the wind speed using the standard atmosphere approximation. This method does not incorporate frictional effects, changes in horizontal location or atmospheric profiles that deviate from the standard atmosphere, for example stable or unstable lower level lapse rates.

A robust analysis of the magnitudes of the various components that may contribute to a step change associated with an in-homogeneity is beyond the scope of this study. Adjustment of monthly means based on the ratio of monthly averages before and after a measurement change is susceptible to being confused with natural interannual variability. Therefore any analysis on long-term trends will be confined to the portions of the climatology with minimal change in observing routine and homogenization of the wind data will not be attempted.

All the trend analysis values in the paper were obtained using the Kendall’s tau test for trend and associated p-values.

5. 3.2 Historical measured winds

The prevailing wind over North America is generally westerly. However, local topography has an influence on the wind direction at any given location. The individual stations sites for our study area have a wide variety of mean annual wind speeds and directions.

Burgeo and Port aux Basques are influenced by cold air dammed along the mountains and funnelling from the fjords along the south coast of Newfoundland. These topographical effects cause prevailing winds, especially during the summer, to be easterly. Doherty (1991) described a favourable meteorological pattern that causes the coastal easterlies often observed at Port aux Basques and Burgeo. “Flows from the south or southwest combine with cold sea surface temperatures to produce very stable air in low levels. The stable flow is blocked by the hills along the south coast of Newfoundland resulting in easterly surface winds along the coast”. (Doherty, 1991). Burgeo has a high occurrence of easterly winds especially during the warmer months. Due to higher topography near Port aux Basques than Burgeo, Port aux Basques experiences more
episodes of easterly winds. These terrain effects will likely have an impact in determining any long term trends in the wind climatology of the southwest coast.

Stephenville Airport also has strong topographical forcing on its prevailing winds but not as obvious as Burgeo or Port aux Basques. St. Georges Bay lies directly to the southwest of the observing station causing the prevailing southwesterly winds to blow relatively unimpeded. However the mountains that lie to the north and east of the observing station increase the frequency of easterly winds in two ways.

- Redirection of synoptic scale flow ahead of an approaching low pressure system from the south or southeast direction to the east to northeast direction.
- Katabatic/drainage winds can develop and flow down the mountainsides under clear skies and a weak synoptic scale isobar pattern.

Sydney Airport’s prevailing wind direction is from the southwest quadrant with the wind blowing between south and west 54% of the time. The remaining 46% is spread relatively evenly between west northwest and south southeast. Sydney Airport is the least topographically influenced observing station included in this study (Karn, 2004).

5.3.2.1 Yearly Mean Wind Speeds

<table>
<thead>
<tr>
<th>Station</th>
<th>Trend (kph/Year)</th>
<th>N</th>
<th>p-value**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burgeo (WBF)</td>
<td>-0.14</td>
<td>35</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Port aux Basques (WZB)</td>
<td>+0.078</td>
<td>38</td>
<td>0.003</td>
</tr>
<tr>
<td>Stephenville (YJT)</td>
<td>+0.025</td>
<td>38</td>
<td>0.208</td>
</tr>
<tr>
<td>Sydney (YQY)</td>
<td>-0.13</td>
<td>36</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

** Significant at 5% level.

Table 5.1 Yearly mean wind speeds

Yearly mean wind speeds were calculated for all for observing stations by summing all hourly observations for a calendar year and dividing by the number of observations. The results are presented in Table 5.1. All statistical significance tests were conducted at the 5% level.
Figure 5.7 Yearly average wind speed, Burgeo

Figure 5.8 Yearly average wind speed, Port-aux-Basques

Figure 5.9 Yearly average wind speed, Stephenville
The results for Burgeo and Sydney Airport indicate a statistically significant decreasing trend while Port aux Basques has a statistically significant increasing trend. The p-values for these trend lines were very small. The slight increasing trend at Stephenville is not statistically significant.

### 5.3.2.2 Yearly Maximum Wind Speeds

<table>
<thead>
<tr>
<th>Station</th>
<th>Trend (kph/Year)</th>
<th>N</th>
<th>p-value**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burgeo (WBF)</td>
<td>&lt;.001</td>
<td>35</td>
<td>0.81</td>
</tr>
<tr>
<td>Port aux Basques (WZB)</td>
<td>+.0.50</td>
<td>38</td>
<td>0.023</td>
</tr>
<tr>
<td>Stephenville (YJT)</td>
<td>0</td>
<td>38</td>
<td>0.69</td>
</tr>
<tr>
<td>Sydney (YQY)</td>
<td>-0.40</td>
<td>36</td>
<td>0.002</td>
</tr>
</tbody>
</table>

** Significant at 5% level.

Table 5.2. Yearly maximum wind speeds

Yearly maximum wind speeds were determined for the stations by selecting the maximum wind speed for a calendar year. The results are presented in Table 5.2. All significance tests were conducted at the 5% significance level.

The overall trends for yearly maximum wind speeds in table 2 are consistent with the yearly mean wind speeds in table 1 where the results for Burgeo and Sydney Airport indicated a decreasing trend while Port aux Basques had an increasing trend. However,
Figure 5.11 Yearly maximum wind speed, Burgeo

Figure 5.12 Yearly maximum wind speed, Port aux Basques

Figure 5.13 Yearly maximum wind speed, Stephenville
the slight decreasing trend at Burgeo is not considered to be statistically significant at the 5% level whereas Sydney’s decreasing trend is statistically significant with a p-value of .002. There was no trend observed in Stephenville's data however it is not statistically significant at the 5% level. Both Port aux Basques and Sydney’s trends are in the opposite direction but both are statistically significant at the 5% level.

5.3.2.3 Annual Wind Speed Category Percentages

Annual wind speeds are divided into four categories: <19 knots, strong [19 to 33 knots], gale force [34 to 47 knots] and storm force [48 to 63]. Sustained hurricane force winds rarely happen so they have not been included in these figures. However when sustained storm force winds are measured they are often accompanied by hurricane force wind gusts.

Table 5.3 contains results of the statistical analysis on the annual wind data using the Kendall Tau test for trend. The results show that the majority of the change that has been analyzed in the annual mean wind speeds is a result of a redistribution of winds in the <19 knots and the strong categories. Changes in gale force winds have had less obvious trends and they tend to be an order of magnitude smaller. Trends in storm force winds are 2 orders of magnitude smaller.
Table 5.3.

<table>
<thead>
<tr>
<th>Station/Category</th>
<th>Trend (%/Year)</th>
<th>N</th>
<th>p-value**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burgeo &lt; 19 knots</td>
<td>+0.250</td>
<td>35</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Burgeo Strong</td>
<td>-0.233</td>
<td>35</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Burgeo Gale force</td>
<td>-0.011</td>
<td>35</td>
<td>0.120</td>
</tr>
<tr>
<td>Burgeo Storm force</td>
<td>0</td>
<td>35</td>
<td>0.629</td>
</tr>
<tr>
<td>Port aux Basques &lt; 19 knots</td>
<td>-0.19</td>
<td>38</td>
<td>0.066</td>
</tr>
<tr>
<td>Port aux Basques Strong</td>
<td>+0.147</td>
<td>38</td>
<td>0.019</td>
</tr>
<tr>
<td>Port aux Basques Gale force</td>
<td>+0.043</td>
<td>38</td>
<td>0.007</td>
</tr>
<tr>
<td>Port aux Basques Storm force</td>
<td>+0.005</td>
<td>38</td>
<td>0.001</td>
</tr>
<tr>
<td>Stephenville &lt; 19 knots</td>
<td>-0.021</td>
<td>38</td>
<td>0.249</td>
</tr>
<tr>
<td>Stephenville Strong</td>
<td>+0.025</td>
<td>38</td>
<td>0.247</td>
</tr>
<tr>
<td>Stephenville Gale force</td>
<td>&lt; -0.001</td>
<td>38</td>
<td>0.939</td>
</tr>
<tr>
<td>Stephenville Storm force</td>
<td>&lt; -0.001</td>
<td>38</td>
<td>0.628</td>
</tr>
<tr>
<td>Sydney &lt; 19 knots</td>
<td>+0.15</td>
<td>36</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sydney Strong</td>
<td>-0.15</td>
<td>36</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sydney Gale force</td>
<td>-0.005</td>
<td>36</td>
<td>0.001</td>
</tr>
<tr>
<td>Sydney Storm force</td>
<td>Insufficient Data</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** Significant at 5% level.

**5.3.2.4 Seasonal Wind Speed Category Percentages**

Seasonal wind speed category graphs are presented in Appendix B and divided into four categories: <19 knots, strong [19 to 33 knots], gale force [34 to 47 knots] and storm force [48 to 63]. Sustained hurricane force winds have not been included. The seasonal wind categories were calculated using climate data counts of the number of
times a wind speed fell within the desired category. The seasonal totals were obtained and divided by the total number of observations and multiplied by 100 to obtain the percentage of occurrence. Tables 5.4A to 5.4D contain results of the statistical analysis on the seasonal wind data using the Kendall Tau test for trend. The majority of change is due to the redistribution of winds between the <19 knots and the strong wind categories. This is particularly evident in the summer and fall and is due to the seasonal cycle to lower wind speeds. In the warmer months the higher wind speed categories have insufficient data to determine a trend for most stations.

5.3.3 Comments on the Seasonal Wind Speed Categories

The analysis for Burgeo indicates a statistically significant increasing trend in the <19 knots category and a statistically significant decreasing trend for most of the higher wind categories for all months. The exceptions occur in the spring and fall where the gale wind category has a decreasing trend that is not statistically significant.

The analysis for Port aux Basques indicates a decreasing trend in the <19 knots category and an increasing trend for the higher wind speed categories. The gale force wind category indicates a statistically significant increasing trend for all seasons.

When the trend analysis is applied to the data between 1990 and 2002 for Port aux Basques, there is a statistically significant decreasing trend for the <19 knots category and a statistically significant increasing trend for the higher wind categories for most seasons.

The analysis for Stephenville indicates a decreasing trend for the <19 knots category and increasing trend for the higher wind speed categories however the trends in all months are not statistically significant at the 5% level.

The analysis for Sydney indicates there is a statistically significant increasing trend in the <19 knots category and a statistically significant decreasing trend for the higher wind categories for all months.
### Seasonal Trends DJF

<table>
<thead>
<tr>
<th>Station/Category</th>
<th>Trend (%/Season)</th>
<th>N</th>
<th>P-Value **</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burgeo &lt; 19 knots</td>
<td>+.242</td>
<td>35</td>
<td>0.010</td>
</tr>
<tr>
<td>Burgeo Strong</td>
<td>-0.224</td>
<td>35</td>
<td>0.009</td>
</tr>
<tr>
<td>Burgeo Gale force</td>
<td>-0.038</td>
<td>35</td>
<td>0.10</td>
</tr>
<tr>
<td>Burgeo Storm force</td>
<td>0.00</td>
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<td>0.579</td>
</tr>
<tr>
<td>Port aux Basques &lt; 19 knots</td>
<td>-0.151</td>
<td>38</td>
<td>0.289</td>
</tr>
<tr>
<td>Port aux Basques Strong</td>
<td>+0.102</td>
<td>38</td>
<td>0.320</td>
</tr>
<tr>
<td>Port aux Basques Gale force</td>
<td>+0.10</td>
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<td>0.024</td>
</tr>
<tr>
<td>Port aux Basques Storm force</td>
<td>+0.002</td>
<td>38</td>
<td>0.260</td>
</tr>
<tr>
<td>Stephenville &lt; 19 knots</td>
<td>-0.082</td>
<td>38</td>
<td>0.204</td>
</tr>
<tr>
<td>Stephenville Strong</td>
<td>+0.079</td>
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<td>0.148</td>
</tr>
<tr>
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</tr>
<tr>
<td>Stephenville Storm force</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Sydney &lt; 19 knots</td>
<td>+0.224</td>
<td>36</td>
<td>0.001</td>
</tr>
<tr>
<td>Sydney Strong</td>
<td>-0.212</td>
<td>36</td>
<td>0.002</td>
</tr>
<tr>
<td>Sydney Gale force</td>
<td>-0.012</td>
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<td>&lt;0.001</td>
</tr>
<tr>
<td>Sydney Storm force</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

* **Significant at 5% level.*
Table 5.4B.

<table>
<thead>
<tr>
<th>Station/Category</th>
<th>Trend (%/Season)</th>
<th>N</th>
<th>P-Value**</th>
</tr>
</thead>
<tbody>
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<td>Burgeo &lt; 19 knots</td>
<td>+0.254</td>
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<td>0.002</td>
</tr>
<tr>
<td>Burgeo Strong</td>
<td>-0.256</td>
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<td>0.001</td>
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<tr>
<td>Burgeo Gale force</td>
<td>-0.008</td>
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<td>0.56</td>
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<td>Burgeo Storm force</td>
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</tr>
<tr>
<td>Port aux Basques &lt; 19 knots</td>
<td>-0.205</td>
<td>38</td>
<td>0.105</td>
</tr>
<tr>
<td>Port aux Basques Strong</td>
<td>+0.152</td>
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<td>0.133</td>
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<td>Port aux Basques Gale force</td>
<td>+0.027</td>
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<td>0.036</td>
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<tr>
<td>Port aux Basques Storm force</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Stephenville &lt; 19 knots</td>
<td>-0.012</td>
<td>38</td>
<td>0.831</td>
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<tr>
<td>Stephenville Strong</td>
<td>+0.008</td>
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<td>0.870</td>
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<td>Stephenville Gale force</td>
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<td>0.870</td>
</tr>
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<td>Stephenville Storm force</td>
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<td></td>
</tr>
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<td>Sydney &lt; 19 knots</td>
<td>+0.196</td>
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<td>&lt;0.001</td>
</tr>
<tr>
<td>Sydney Strong</td>
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<td>&lt;0.001</td>
</tr>
<tr>
<td>Sydney Gale force</td>
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<td></td>
</tr>
<tr>
<td>Sydney Storm force</td>
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</tr>
</tbody>
</table>

** Significant at 5% level.
### Table 5.4C.

**Seasonal Trends JJA**

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<tr>
<th>Station/Category</th>
<th>Trend (%/Season)</th>
<th>N</th>
<th>P-Value**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burgeo &lt; 19 knots</td>
<td>+0.129</td>
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<td>&lt;0.001</td>
</tr>
<tr>
<td>Burgeo Strong</td>
<td>-0.107</td>
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<td>0.001</td>
</tr>
<tr>
<td>Burgeo Gale force</td>
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<tr>
<td>Burgeo Storm force</td>
<td>Insufficient data</td>
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</tr>
<tr>
<td>Port aux Basques  &lt; 19 knots</td>
<td>-0.010</td>
<td>38</td>
<td>0.025</td>
</tr>
<tr>
<td>Port aux Basques Strong</td>
<td>+0.100</td>
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<td>0.021</td>
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<td>Port aux Basques Gale force</td>
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<tr>
<td>Port aux Basques Storm force</td>
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<td></td>
<td></td>
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<td>Stephenville &lt; 19 knots</td>
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<td></td>
</tr>
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<td>Sydney &lt; 19 knots</td>
<td>+0.066</td>
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<td>&lt;0.001</td>
</tr>
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<td>Sydney Strong</td>
<td>-0.064</td>
<td>36</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sydney Gale force</td>
<td>Insufficient data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sydney Storm force</td>
<td>Insufficient data</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** Significant at 5% level.
Table 5.4D.

<table>
<thead>
<tr>
<th>Station/Category</th>
<th>Trend (%/Season)</th>
<th>N</th>
<th>P-Value**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burgeo &lt; 19 knots</td>
<td>+0.274</td>
<td>35</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Burgeo Strong</td>
<td>-0.244</td>
<td>35</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Burgeo Gale force</td>
<td>-0.012</td>
<td>35</td>
<td>0.382</td>
</tr>
<tr>
<td>Burgeo Storm force</td>
<td>Insufficient data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port aux Basques &lt; 19 knots</td>
<td>-0.156</td>
<td>38</td>
<td>0.084</td>
</tr>
<tr>
<td>Port aux Basques Strong</td>
<td>+0.117</td>
<td>38</td>
<td>0.132</td>
</tr>
<tr>
<td>Port aux Basques Gale force</td>
<td>+0.032</td>
<td>38</td>
<td>0.018</td>
</tr>
<tr>
<td>Port aux Basques Storm force</td>
<td>Insufficient data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stephenville &lt; 19 knots</td>
<td>-0.009</td>
<td>38</td>
<td>0.660</td>
</tr>
<tr>
<td>Stephenville Strong</td>
<td>+0.012</td>
<td>38</td>
<td>0.610</td>
</tr>
<tr>
<td>Stephenville Gale force</td>
<td>Insufficient data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stephenville Storm force</td>
<td>Insufficient data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sydney &lt; 19 knots</td>
<td>+0.149</td>
<td>36</td>
<td>0.002</td>
</tr>
<tr>
<td>Sydney Strong</td>
<td>-0.145</td>
<td>36</td>
<td>0.002</td>
</tr>
<tr>
<td>Sydney Gale force</td>
<td>Insufficient data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sydney Storm force</td>
<td>Insufficient data</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Significant at 5% level.
Figure 5.15

Burgeo Annual Wind Speed Categories
% Occurrence vs. Year

Year

Figure 5.16

Port aux Basques Annual Wind Speed Categories
% Occurrence vs. Year

Year
5.4 Transportation Interruption Index

Quantitative analysis of long-term trends in mean, maximum and categorical winds does not address the issue of wind event duration. To investigate the possibility of long-term trends in wind event duration, and the relative strength of those events, we have developed a Transportation Interruption Index to help quantify the potential a given year had to interrupt transportation through the Cabot Strait. In our index a wind event is defined as lasting three hours and having a minimum wind speed of 63 kph. The maximum wind speed is then multiplied by the mean wind speed and the resulting product is multiplied by the duration. The total is then divided by a scaling factor of 11,907, the minimum value attainable from the above calculation. Therefore the minimum value of the event, TIIₐ, is 1. The TIIₐ for the calendar year are then summed to create the TII. This formula is also described below:

\[ TIIₐ = \frac{(\text{Max Wind Speed}) \times (\text{Mean Wind Speed}) \times (\text{Duration})}{11907} \]

\[ TII = \sum TIIₐ \]

The TII for Port aux Basques, Burgeo, Stephenville and Sydney are shown in Figures 5.19 to 5.22. The results for Port aux Basques are further broken down to their westerly and easterly components in Figures 5.23 and 5.24. The trend analysis for the TII is shown in Table 5.5.

It is interesting to note the high interannual variability in the TII westerly component compared to the relatively benign easterly. This graph shows quantitatively that although the easterly winds are of concern for the Wreckhouse area, it is the westerlies that have the greatest potential to produce stormy conditions in the Cabot Strait.
Figure 5.19

Yearly Port aux Basques TII
(1966, 1997 & 1998 removed)

Figure 5.20

Yearly Burgeo TII
(1967-69 removed)

Figure 5.21

Yearly Stephenville TII

Figure 5.22

Yearly Sydney TII
(1966-68 removed)
Figure 5.23 Transportation Interruption Index for Wreckhouse, Westerly winds

Figure 5.24 Transportation Interruption Index for Wreckhouse, Easterly Winds
Table 5.5.

<table>
<thead>
<tr>
<th>Station</th>
<th>Trend (per Year)</th>
<th>N</th>
<th>p-value**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burgeo</td>
<td>-1.13</td>
<td>35</td>
<td>0.002</td>
</tr>
<tr>
<td><strong>Burgeo</strong></td>
<td>-0.011</td>
<td>33</td>
<td>0.988</td>
</tr>
<tr>
<td>Port aux Basques</td>
<td>+2.40</td>
<td>36</td>
<td>0.004</td>
</tr>
<tr>
<td>Stephenville</td>
<td>0</td>
<td>38</td>
<td>0.850</td>
</tr>
<tr>
<td>Sydney</td>
<td>-0.139</td>
<td>36</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

** Significant at 5% level.
Burgeo++ - For comparison the extreme data for 1971 & 72 has been removed.

5.5 Wreckhouse Area

Port aux Basques and Wreckhouse are geographically close. However, the topography of southwestern Newfoundland impacts the winds measured at both stations differently, for identical synoptic weather patterns. Chapter 4 contains information on past wind studies of the area that highlight the importance of the Wreckhouse wind.

For years the residents of southwestern Newfoundland and forecasters at the former Newfoundland Weather Centre have known that a relationship exists between easterly winds measured at Port aux Basques and the downslope winds present in the Wreckhouse area. This relationship is shown in a graphical manner in Figures 5.25 and 5.27. The data plotted are hourly observations and the corresponding wind speeds at both observing sites from 2000 to 2004. The wind speeds would be very close in magnitude without the topographical effect caused by the mountains and coastline and the data would be plotted with a slope near one.

Figure 5.25 shows the relationship between the winds at Port aux Basques and Wreckhouse for wind directions northeast to southerly when the mountains along the south coast induce a downslope wind at Wreckhouse. This leads to the general relationship that the winds at Wreckhouse are stronger than those at Port aux Basques for these directions.

Figure 5.26 is for the westerly direction and shows that the winds at Port aux Basques generally blow stronger than the winds at Wreckhouse for a similar synoptic scale weather pattern. This is likely caused by the funnelling and channelling of westerly
Figure 5.25  Relationship between Port aux Basques (WZB) and Wreckhouse (XWR) winds, easterly direction

![Figure 5.25](image)

Figure 5.26  Relationship between Port aux Basques (WZB) and Wreckhouse (XWR) winds, westerly direction

![Figure 5.26](image)
Figure 5.27 Relationship between Port aux Basques and Wreckhouse winds, easterly storm peaks

![Graph showing the relationship between Port aux Basques and Wreckhouse winds, easterly storm peaks. The graph includes a regression line with the equation y = 0.8139x + 42.165 and R^2 = 0.6123.]

Figure 5.28 Inferred Wreckhouse Peak Winds, 1966-2004

![Graph showing inferred Wreckhouse peak winds from 1966 to 2004.]

\[ y = 0.8139x + 42.165 \]
\[ R^2 = 0.6123 \]
winds through the Cabot Strait and the exposure of the Port aux Basques area to this wind direction.

Figure 5.27 displays the relationship differently. Wreckhouse events were identified and the maximum hourly winds at the Port aux Basques observing station was paired with the maximum hourly winds at the Wreckhouse observing station. It should be noted that this is a relationship between hourly winds. There were no gusts analyzed, no special observations included and some outliers were removed.

The linear regression line equation was used to infer the history of Wreckhouse winds from the Port aux Basques wind observation data and the results are presented in Figures 5.28 and 5.29. They show considerable inter-annual and inter-decadal variability in the frequency of Wreckhouse events and the maximum sustained wind expected. However there are no long term increasing or decreasing trends present in the data.

![Wreckhouse Event Total Yearly Hours](image)

Figure 5.29  Wreckhouse Wind event total yearly hours. See Chapter 7 for further discussion.
5.6 Wreckhouse Area Wind Climatology

St. Andrew’s 1953-May 1966
Wreckhouse 2000-2004

In Figures 5.30 to 5.35 a Wreckhouse wind event is defined as having occurred if the mean wind speed reached 75 km/h or more and from directions 080° clockwise to 170° inclusive. Multiple Wreckhouse events could occur for the same synoptic system if the duration of an event was interrupted by 3 or more hours of lighter wind speeds. Wreckhouse events have been observed to last for 16 hours at St. Andrew’s and 22 hours at Wreckhouse. The figures show most Wreckhouse events last longer than 3 hours. Gust data has not been included.

The annual distribution of Wreckhouse events at St. Andrews’ shows much variability ranging from 4 events in 1955 and 1957 to 15 in 1963. Similar variability is observed in six years of data from the Wreckhouse observing station. There were also more events observed at Wreckhouse however these stations should not be compared. The St. Andrew’s data was collected from manned observations and the Wreckhouse data from an automatic weather station. Both stations are separated by several kilometres and used different wind measuring instruments and recording periods.

The monthly distribution of Wreckhouse events is very similar at both locations and this is expected. Wreckhouse events occur most often in the winter and early spring with little or no events during the summer. This is due to the strengthening of the jet stream and synoptic weather systems in the winter and a weakening during the summer.

Meteorologists in Atlantic Canada have known that Wreckhouse windstorms mainly occur with southeast winds ahead of low pressure systems that track west or northwest of the Cabot Strait and much less frequently for ones that track to the southeast (Figure 5.36). This is also evident from the Wreckhouse wind study (Sutherland, 1963) that found 20 percent of the Wreckhouse windstorms occurred when low pressure systems tracked southeast of the Cabot Strait and 80 percent when they travelled to the west or northwest.
Figure 5.30

Yearly Distribution of Wreckhouse Events at St. Andrew’s Maximum Mean Wind Speed >= 75 km/h

Figure 5.31

Monthly Distribution of Wreckhouse Events 1953-1966 at St. Andrew’s Maximum Mean Wind Speed >=75 km/h
Figure 5.32

Total # Observations at St. Andrew’s 1953-1966

Yearly Distribution of Wreckhouse Events at Wreckhouse 2000-2004
Maximum Mean Wind Speed >= 75 km/h
Figure 5.34

**Monthly Distribution of Wreckhouse Events at Wreckhouse 2000-2004**

![Bar chart showing the monthly distribution of events from January 2000 to December 2004.]

- X-axis: Month
  - Jan to Dec
- Y-axis: # Events
  - 0 to 20

Figure 5.35

**Total # Observations at Wreckhouse 2000-2004**

![Bar chart showing the total number of observations from 2000 to 2004.]

- X-axis: Year
  - 2000 to 2004
- Y-axis: # Observations
  - 7200 to 9000

Year 2000: 7200
Year 2001: 8600
Year 2002: 9000
Year 2003: 9000
Year 2004: 8000
Tables 5.6A and 5.6B highlight the significance of the Wreckhouse winds in the Codroy Valley. All maximum annual average wind speeds (all directions), at St. Andrew’s and Wreckhouse, occurred during Wreckhouse wind events.

Table 5.6A.
Maximum Annual Average Wind Speed
St. Andrew’s, NL 1953-1966

<table>
<thead>
<tr>
<th>YEAR</th>
<th>Wind Speed (km/h) (1 Hour Average) Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1953</td>
<td>140º@ 97</td>
</tr>
<tr>
<td>1954</td>
<td>140º@ 97</td>
</tr>
<tr>
<td>1955</td>
<td>140º@ 100</td>
</tr>
<tr>
<td>1956</td>
<td>160º@ 105</td>
</tr>
<tr>
<td>1957</td>
<td>110º@ 129</td>
</tr>
<tr>
<td>1958</td>
<td>160º@ 116</td>
</tr>
<tr>
<td>1959</td>
<td>140º@ 145</td>
</tr>
<tr>
<td>1960</td>
<td>180º@ 121</td>
</tr>
<tr>
<td>1961</td>
<td>110º@ 145</td>
</tr>
<tr>
<td>1962</td>
<td>140º@ 97</td>
</tr>
<tr>
<td>1963</td>
<td>140º@ 129</td>
</tr>
<tr>
<td>1964</td>
<td>140º@ 126</td>
</tr>
<tr>
<td>1965</td>
<td>110º@ 113</td>
</tr>
<tr>
<td>1966 Jan-May</td>
<td>110º@ 89</td>
</tr>
</tbody>
</table>
5.6B. Table 5.6B.

**Maximum Annual Average Wind Speed**

**Wreckhouse, NL 2000-2005**

<table>
<thead>
<tr>
<th>YEAR</th>
<th>Wind Speed (km/h)</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>100° @ 128</td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>110° @ 120</td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>120° @ 120</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>130° @ 126</td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>090° @ 122</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>100° @ 110</td>
<td></td>
</tr>
</tbody>
</table>

5.7 AES40 Model data

Figures 5.37 and 5.38 show the annual average and maximum wind speeds, respectively, for the AES40 data point. The results of the statistical analysis are presented in Table 5.7. There is a statistically increasing trend for the average yearly wind over the period 1955 to 2002. When the 1967 to 2002 time period, roughly the same time that the data from the observation network is being considered, the statistical significance is lost and the trend resembles the one in the Stephenville Airport dataset.

Table 5.7.

<table>
<thead>
<tr>
<th>AES40</th>
<th>Trend (kph/Year)</th>
<th>N</th>
<th>p-value **</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yearly Average (1955-2002)</td>
<td>+0.028</td>
<td>48</td>
<td>0.032</td>
</tr>
<tr>
<td>Yearly Maximum (1955-2002)</td>
<td>+0.106</td>
<td>48</td>
<td>0.080</td>
</tr>
<tr>
<td>Yearly Average (1967-2002)</td>
<td>+0.007</td>
<td>36</td>
<td>0.733</td>
</tr>
<tr>
<td>Yearly Maximum (1967-2002)</td>
<td>-0.004</td>
<td>36</td>
<td>0.859</td>
</tr>
</tbody>
</table>

** Significant at 5% level.

Figure 5.39 shows the mean daily maximum wind for winter (DJF) and (figure 10.6) shows the annual frequency of gale force or greater winds. The analysis is given in Table 5.7A. Figures 5.40 and 5.41 show box plots of winter daily maximum winds and monthly maximum winds, respectively. The lack of statistical significance shown in Table 5.7A
Figure 5.37

AES 40 Yearly Average Wind Speed

![AES 40 Yearly Average Wind Speed Graph](image)

Figure 5.38

AES 40 Yearly Maximum Wind Speed

![AES 40 Yearly Maximum Wind Speed Graph](image)
Figure 5.39

AES 40 Mean Winter Daily Max Wind

Year

kph


30 35 40 45 50 55

Figure 5.40

AES40 Winter Daily Max Winds

Year

Daily Max (kph)

0 20 40 60 80 100

can also be seen in these plots with considerable interannual variability but no clear trend is evident.
AES40 yearly wind speeds were sorted into marine wind categories for a calendar year. The results are presented in Figure 5.43 and the statistical analysis is presented in table 5.8. All significance tests were conducted at the 5% significance level.

**Table 5.7a.**

<table>
<thead>
<tr>
<th>AES40 Wind Trends</th>
<th>Trend (+/-)</th>
<th>N</th>
<th>p-value **</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Winter (DJF) Maximum Wind</td>
<td>+</td>
<td>48</td>
<td>0.294</td>
</tr>
<tr>
<td>Annual Frequency of Wind &gt;= 34 knots</td>
<td>+</td>
<td>48</td>
<td>0.227</td>
</tr>
</tbody>
</table>

**Figure 5.43**

AES40 Annual Wind Speed Categories

**Table 5.8.**

<table>
<thead>
<tr>
<th>Wind Category 1955-2002</th>
<th>Trend (kph/Year)</th>
<th>N</th>
<th>p-value **</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; Strong (19 knots)</td>
<td>-0.080</td>
<td>48</td>
<td>0.032</td>
</tr>
<tr>
<td>Strong (19 to 33 knots)</td>
<td>+0.080</td>
<td>48</td>
<td>0.029</td>
</tr>
<tr>
<td>&gt;= Gale (34 knots)</td>
<td>+0.006</td>
<td>48</td>
<td>0.380</td>
</tr>
</tbody>
</table>

**Significant at 5% level.**
The result for the strong category indicates a statistically significant increasing trend while the less than strong category has a statistically significant decreasing trend. The p-values for these regression lines were 0.029 and 0.032 respectively. The increasing trend for the gale force or greater category is not statistically significant at the 5% level. This analysis indicates an overall decrease in weaker winds but it does not translate into an increased frequency of more extreme winds.

An analysis of the AES40 wave data set for the Cabot Strait is presented in Figures 5.44 and 5.45. The results are summarized in Table 5.9.

Figure 5.44

![Yearly Peak Sig and Max Wave Height](image1)

Figure 5.45

![Yearly Count of Wave >= 4 m](image2)
Table 5.9.

<table>
<thead>
<tr>
<th>Yearly AES40 wave value 1955-2002</th>
<th>TREND cm/yr</th>
<th>N</th>
<th>p-value **</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Maximum wave height</td>
<td>+0.070</td>
<td>48</td>
<td>0.002</td>
</tr>
<tr>
<td>Peak Significant wave height</td>
<td>+0.035</td>
<td>48</td>
<td>0.005</td>
</tr>
<tr>
<td>Count of Waves &gt;= 4 metres</td>
<td>0.00</td>
<td>48</td>
<td>0.850</td>
</tr>
</tbody>
</table>

** Significant at 5% level.

The result for the peak yearly maximum and significant wave height categories indicate a statistically significant increasing trend. The annual count of significant wave heights greater than 4 metres show no trend that is not statistically significant.

5.8  Environment Canada 100 Year (1901 - 2000) Tropical Cyclone Climatology

Few meteorological phenomena capture the attention of meteorologists, the media and the general public as hurricanes do. Images of these storms charting their way through the Gulf of Mexico causing the evacuation of millions of people have a way of leaving an impression. Eventually many of these storms make their way to Atlantic Canada near south-western Newfoundland (Figure 5.46) where they can take many forms. The most common scenarios for a tropical cyclone that passes through Atlantic Canada is to weaken as it crosses eastern North America or weaken over the cold waters of the North Atlantic. In these cases the winds will diminish considerably below hurricane strength and the widespread torrential rain will diminish to areas of heavy showers. Hurricane Ophelia (2005) is a good example.

However there are scenarios when these storms maintain their strength and make landfall as full-fledged hurricanes or interact with processes in the upper atmosphere that will cause intensification. These storms are accompanied by torrential rains, hurricane force winds and damaging waves and storm surge. In October 2000 hurricane Michael made landfall on the south coast of Newfoundland as a category one hurricane.
Environment Canada has analyzed 100 years of tropical cyclone tracks as they pass through Atlantic Canada and recorded when these storms pass within 260 kilometres of 33 different locations. We have decided to use the criteria of a tropical cyclone passing within 260 kilometres of Sydney or Port aux Basques to determine when a tropical cyclone might impact travel through the Cabot Strait or southwestern Newfoundland. The results are shown in Figures 5.47 and 5.48. Figure 5.47 shows the monthly frequency distribution of tropical cyclone activity with September being the most active month. Figure 5.48 shows the annual frequency of tropical cyclone activity over 100 years. An active year consists of 3 storms and many years in which no storms pass within 260 km of the Cabot Strait area. There is no obvious trend in tropical cyclone activity over the study area.
5.9 Discussion: Inhomogeneous Data

In order to draw as much trend information from the data as possible the inhomogeneities in the data, documented and perhaps otherwise, need to be considered. To determine if a change in wind speed is related to changes in the physical environment or changes in the observation history it is helpful to determine when the wind speed changed. If the change corresponds with an observation method or location change it raises the possibility that the increase or decrease in wind speed is not entirely natural but
caused by the non-homogeneous nature of the measurements. A double mass curve is an arithmetic plot of the accumulated values of observations of two variables that are paired in time and thought to be related. As long as the relationship remains constant the double-mass curve will appear as a straight line; a deviation denotes the timing of a change\(^1\). The annual percentages of strong winds for our observation sites where inhomogeneities exist are compared to the annual percentages of strong winds AES40 data set where inhomogeneities do not exist. Results are displayed in Figures 5.49 to 5.53.

Figure 5.49 shows the accumulated annual percentages of strong winds for all 4 sites plus the AES40 site. Note the relative consistent slope of the AES40 data when compared to the historical climatological data.

Figure 5.50, Burgeo indicates changes in 1975, 1979, 1985 and 1993. However none of these inflexion points correspond to dates of change in the site history.

Figure 5.51, Port aux Basques indicates changes in 1972, 1980, 1984, 1992 and 1997. There were changes to site history in 1983, 1991 and 1998.

Figure 5.52, Sydney indicates changes in 1971, 1978, 1982, 1989 and 1993 and possible more.

Figure 5.53, Stephenville indicates slight changes in 1974, 1988, 1994 and 1996. None of these inflexion points correspond to dates of changes as indicated by the inspector reports.

From the analysis of the double mass curve it appears the wind data observed at Stephenville has the highest probability of being the least affected by the documented inhomogeneities in its observational history. The changes present in its curve do not correspond to the documented changes in observing method or location. The observations at Burgeo also have a high probability of not being affected by the documented changes in observing method but there seems to be a significant and persistent reduction in the percentage of strong winds beginning in the mid 1980s. This could be a natural reduction in the local winds or the result of changes in the physical environment that are not documented in the inspector’s reports. The changes in the Port aux Basques curve correspond to changes in observing method. Changes in Sydney’s curve are so dramatic it

\(^1\) [http://amsglossary.allenpress.com/glossary](http://amsglossary.allenpress.com/glossary)
is hard to imagine such changes occurring naturally in such a short period of time. Accordingly the Stephenville and Burgeo historical data will be given the greatest weight when determining the presence of long term trends.

5.9 Summary of Overall Trends

Our analysis of the wind regime for southwestern Newfoundland and the Cabot Strait included an analysis of historical and model derived climatological data, model derived wave statistics and data presented in Environment Canada's 100 year tropical cyclone climatology for the last 35 to 50 years. A considerable portion of our analysis indicates that there is no trend in extreme wind events for the area.

5.9.1 WBF, YJT and AES40 wind data

The climatology of historical wind data from Stephenville and Burgeo and the AES40 model derived climatological data presented does not indicate a clear trend in the historical mean or extreme wind conditions of southwest Newfoundland and the Cabot Strait.

- The yearly average wind observed at Burgeo has a statistically significant decreasing trend. However, between 1986 and 1990 the annual percentage of strong winds significantly decreases and there is an equally dramatic increase in the percentage of less than strong winds. It appears that a significant and permanent inhomogeneity may have been introduced into the data during that period that has not been documented.
- The increasing trend in the maximum yearly wind at Burgeo is not statistically significant.
- Stephenville’s trends are increasing for yearly average and maximum winds but they are not statistically significant at the 95% confidence level.
- The AES40 data has a statistically significant increasing trend in yearly average winds. However the increasing trend in maximum winds is not statistically
significant at the 95% confidence level when considering the entire data set. When the data pre-1966 is removed, i.e. the time period being analyzed is the same as Stephenville and Burgeo, the statistical significance is lost and the overall trend is similar to Stephenville’s.

- When the duration and intensity of individual wind events for Burgeo and Stephenville are considered, by analyzing the TII, the trends emulate the trends in the mean winds. Burgeo’s TII decreasing over time and Stephenville with no significant trend. However, when the 2 extreme years are removed from the early period of Burgeo’s time series for comparison, the statistical significance is lost and it gives the same answer as the Stephenville TII analysis.

5.9.2 AES40 wave data

The results for the wave data emulate the wind data such that the maximum data, yearly peak maximum wave height and the annual count of significant wave heights greater than 4 metres are not statistically significant. However the mean annual significant wave height, like the mean average wind, does show a slight, statistically significant, increasing trend

5.9.3 Wreckhouse data

The data show considerable inter-annual and inter-decadal variability in the frequency of Wreckhouse events and the maximum sustained wind expected. However, there are no long term trends present in the data.

5.9.4 100 year tropical storm climatology data

There has been no clear scientifically determined consensus that tropical cyclones are increasing in frequency or intensity. Active and in-active periods for tropical cyclones in the Atlantic basin last between 25 and 40 years each and it is possible that we are 10 years into an active cycle (Chris Landsea, http://www.aoml.noaa.gov/hrd/tcfaq/G4.html).
The data for the Cabot Strait area that has been analyzed confirms the large inter-annual and inter-decadal variability in tropical storm frequency with no clear long term trend present.

5.11 Acknowledgements

We would like to acknowledge the following people who greatly aided in the preparation of this report:

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- Dr. Leonard Lye, Memorial University of Newfoundland.
- Doug Mercer, George Parkes, Ming Szeto, Bruce Whiffen and Bridget Thomas of Environment Canada, Atlantic Region.
- Peter Bowyer, Canadian Hurricane Centre
- Kevin Pike, Environmental Protection
6. The Value of Economic Loss Associated with Weather-Related Delays on the North Sydney-Port aux Basques Marine Transportation Link in 2003 and 2004

Wade Locke

6.1 Introduction

This report was prepared as part of the study entitled: Storm and Wind Impacts on Transportation, Southwest Newfoundland. The purpose of this report is to estimate the economic loss associated with weather-related delays associated with Marine Atlantic’s marine transportation service between North Sydney, Nova Scotia and Port aux Basques, Newfoundland and Labrador.

The economic costs associated with weather related delays on the North Sydney-Port aux Basques run averaged $3.5 million per year. The estimates for each year were:

- $2.1 million in 2003; and
- $4.9 million in 2004

6.2 Methodology and Results

There are no published data available on the number and duration of weather-related delays or on the number of passengers or commercial vehicles affected by these delays for the marine transportation link between North Sydney, Nova Scotia and Port aux Basques, Newfoundland and Labrador. However, Marine Atlantic records a daily Situation Report for the ships that it operates on this run.2 For the purpose of this study, Marine Atlantic provided the 2003 and 2004 Situation Reports for both the Port aux Basques and North Sydney ports. This meant that 1,462 reports were reviewed and analyzed for this study3.

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2 The four ships that provided marine transportation services between Port aux Basques and North Sydney between 2003 and 2004 were: the MV Caribou, the MV Joseph and Clara Smallwood, the MV Leif Ericson and the MV Atlantic Freighter.
3 All data are available from Norm Catto on request.
These reports indicated for each day of the year and for all of the ships involved in this route the following information:

- the number of passengers;
- the number of passenger-related vehicles;
- the number of commercial vehicles;
- the time of departure and the time of arrival; and
- whether the ship was late leaving or arriving and the reason why, including specifying weather-related delays.

For each of the ships operating on the Nova Scotia/Newfoundland and Labrador run, it is possible to determine the number of weather-related delays and their duration. In addition, it is possible to determine the number of passengers and commercial traffic that was affected by these delays. Because of the normal variation in sailing times, only delays of two hours or more are included in this analysis.

For each weather-related delay of two hour or more, the corresponding number of passengers and commercial vehicles are recorded. As well for each delay, the number of passenger hours are calculated as the product of the number of passengers and the number of hours involved in that specific delay. Similarly, the number of commercial vehicle hours is calculated as the product of the number of commercial vehicles involved in the delay times the number of hours associated with the delay. This information is presented in Table 6.1.
Table 6.1: Weather Related Delays on the North Sydney-Port aux Basques Run for Marine Atlantic in 2003 and 2004

<table>
<thead>
<tr>
<th>Ship</th>
<th>Delay Hours</th>
<th>Passengers</th>
<th>Commercial Vehicles</th>
<th>Passengers Hours</th>
<th>Commercial Vehicles Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caribou</td>
<td>168</td>
<td>2,414</td>
<td>918</td>
<td>25,388</td>
<td>9,706</td>
</tr>
<tr>
<td>Smallwood</td>
<td>257</td>
<td>2,266</td>
<td>730</td>
<td>35,733</td>
<td>14,303</td>
</tr>
<tr>
<td>Atlantic Freighter</td>
<td>3</td>
<td>6</td>
<td>61</td>
<td>18</td>
<td>183</td>
</tr>
<tr>
<td>Leif Ericson</td>
<td>232</td>
<td>1,881</td>
<td>946</td>
<td>22,298</td>
<td>12,099</td>
</tr>
<tr>
<td><strong>Combined</strong></td>
<td><strong>660</strong></td>
<td><strong>6,567</strong></td>
<td><strong>2,655</strong></td>
<td><strong>83,437</strong></td>
<td><strong>36,291</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ship</th>
<th>Delay Hours</th>
<th>Passengers</th>
<th>Commercial Vehicles</th>
<th>Passengers Hours</th>
<th>Commercial Vehicles Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caribou</td>
<td>417</td>
<td>4,061</td>
<td>1,251</td>
<td>83,665</td>
<td>22,244</td>
</tr>
<tr>
<td>Smallwood</td>
<td>461</td>
<td>4,185</td>
<td>1,724</td>
<td>70,177</td>
<td>25,806</td>
</tr>
<tr>
<td>Atlantic Freighter</td>
<td>150</td>
<td>60</td>
<td>421</td>
<td>1,106</td>
<td>7,072</td>
</tr>
<tr>
<td>Leif Ericson</td>
<td>349</td>
<td>2,300</td>
<td>862</td>
<td>50,818</td>
<td>18,955</td>
</tr>
<tr>
<td><strong>Combined</strong></td>
<td><strong>1,377</strong></td>
<td><strong>10,606</strong></td>
<td><strong>4,258</strong></td>
<td><strong>205,766</strong></td>
<td><strong>74,077</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ship</th>
<th>Delay Hours</th>
<th>Passengers</th>
<th>Commercial Vehicles</th>
<th>Passengers Hours</th>
<th>Commercial Vehicles Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caribou</td>
<td>292</td>
<td>3,238</td>
<td>1,085</td>
<td>54,526</td>
<td>15,975</td>
</tr>
<tr>
<td>Smallwood</td>
<td>359</td>
<td>3,226</td>
<td>1,227</td>
<td>52,955</td>
<td>20,055</td>
</tr>
<tr>
<td>Atlantic Freighter</td>
<td>77</td>
<td>33</td>
<td>241</td>
<td>562</td>
<td>3,628</td>
</tr>
<tr>
<td>Leif Ericson</td>
<td>291</td>
<td>2,091</td>
<td>904</td>
<td>36,558</td>
<td>15,527</td>
</tr>
<tr>
<td><strong>Combined</strong></td>
<td><strong>1,018</strong></td>
<td><strong>8,587</strong></td>
<td><strong>3,457</strong></td>
<td><strong>144,601</strong></td>
<td><strong>55,184</strong></td>
</tr>
</tbody>
</table>

The next step involved trying to assign a value to the lost time associated with these weather-related delays. In this analysis, it is assumed that the economic value of a specific unit of time saved from transportation projects is equivalent to, but of opposite sign, for the same-sized unit of time lost due to weather-related delays.

Transport Canada, in their Guide to Benefit-Cost Analysis suggests using $24.00 per hour in 1990 dollars for the value of business travel by automobile saved from transportation projects in Canada and using $9.10 per hour in 1990 dollars where “reliable information on trip purpose (i.e., business/non-business) is not available.” Since there is no data on which of the passengers are traveling for business or other purposes, the $9.10 per is used to value the lost time for passengers caused by the weather delay. The lost time associated with commercial vehicles is valued at $24.00 per hour. In order to take into account the level of inflation that has occurred between 1990 and 2003 and

---

2004, these dollar estimates are adjusted to their 2003 and 2004 equivalents utilizing the Consumer Price Index for Canada (1992=100). Making these adjustments yields:

- $11.93 per hour for passengers and $31.46 for commercial vehicles in 2003; and
- $12.15 per hour for passengers and $32.05 for commercial vehicles in 2005.

Applying these values to the weather-related delays generates the economic value of the lost time on the North Sydney-Port aux Basques run as a result of weather in 2003 and 2004. These estimates are presented in the following table.

Table 6.2: Value of Weather Related Delays on the North Sydney-Port aux Basques Run for Marine Atlantic in 2003 and 2004

<table>
<thead>
<tr>
<th>Ship</th>
<th>Passengers Hours</th>
<th>Commercial Vehicles Hours</th>
<th>Dollar Value of Passengers Delays</th>
<th>Dollar Value of Commercial Vehicles Delays</th>
<th>Total Value of Weather Delays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caribou</td>
<td>25,388</td>
<td>9,706</td>
<td>$302,879</td>
<td>$305,351</td>
<td>$608,230</td>
</tr>
<tr>
<td>Smallwood</td>
<td>35,733</td>
<td>14,303</td>
<td>$426,295</td>
<td>$449,972</td>
<td>$876,267</td>
</tr>
<tr>
<td>Atlantic Freighter</td>
<td>18</td>
<td>183</td>
<td>$215</td>
<td>$5,757</td>
<td>$5,972</td>
</tr>
<tr>
<td>Leif Ericson</td>
<td>22,298</td>
<td>12,099</td>
<td>$266,015</td>
<td>$380,635</td>
<td>$646,650</td>
</tr>
<tr>
<td><strong>Combined</strong></td>
<td><strong>83,437</strong></td>
<td><strong>36,291</strong></td>
<td><strong>$995,403</strong></td>
<td><strong>$1,141,715</strong></td>
<td><strong>$2,137,118</strong></td>
</tr>
</tbody>
</table>

Year – 2003

<table>
<thead>
<tr>
<th>Ship</th>
<th>Passengers Hours</th>
<th>Commercial Vehicles Hours</th>
<th>Dollar Value of Passengers Delays</th>
<th>Dollar Value of Commercial Vehicles Delays</th>
<th>Total Value of Weather Delays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caribou</td>
<td>83,665</td>
<td>22,244</td>
<td>$1,016,524</td>
<td>$712,904</td>
<td>$1,729,428</td>
</tr>
<tr>
<td>Smallwood</td>
<td>70,177</td>
<td>25,806</td>
<td>$852,651</td>
<td>$827,082</td>
<td>$1,679,733</td>
</tr>
<tr>
<td>Atlantic Freighter</td>
<td>1,106</td>
<td>7,072</td>
<td>$13,438</td>
<td>$226,658</td>
<td>$240,096</td>
</tr>
<tr>
<td>Leif Ericson</td>
<td>50,818</td>
<td>18,955</td>
<td>$617,439</td>
<td>$607,508</td>
<td>$1,224,946</td>
</tr>
<tr>
<td><strong>Combined</strong></td>
<td><strong>205,766</strong></td>
<td><strong>74,077</strong></td>
<td><strong>$2,500,051</strong></td>
<td><strong>$2,374,152</strong></td>
<td><strong>$4,874,203</strong></td>
</tr>
</tbody>
</table>

Year – 2004

<table>
<thead>
<tr>
<th>Ship</th>
<th>Passengers Hours</th>
<th>Commercial Vehicles Hours</th>
<th>Dollar Value of Passengers Delays</th>
<th>Dollar Value of Commercial Vehicles Delays</th>
<th>Total Value of Weather Delays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caribou</td>
<td>54,526</td>
<td>15,975</td>
<td>$659,701</td>
<td>$509,127</td>
<td>$1,168,829</td>
</tr>
<tr>
<td>Smallwood</td>
<td>52,955</td>
<td>20,055</td>
<td>$639,473</td>
<td>$638,527</td>
<td>$1,278,000</td>
</tr>
<tr>
<td>Atlantic Freighter</td>
<td>562</td>
<td>3,628</td>
<td>$6,826</td>
<td>$116,207</td>
<td>$123,034</td>
</tr>
<tr>
<td>Leif Ericson</td>
<td>36,558</td>
<td>15,527</td>
<td>$441,727</td>
<td>$494,071</td>
<td>$935,798</td>
</tr>
<tr>
<td><strong>Combined</strong></td>
<td><strong>144,601</strong></td>
<td><strong>55,184</strong></td>
<td><strong>$1,747,727</strong></td>
<td><strong>$1,757,933</strong></td>
<td><strong>$3,505,660</strong></td>
</tr>
</tbody>
</table>

5 The CPI (1992=100) was 93.3 in 1990, 122.3 in 2003 and 124.6 in 2004.
6.3 Conclusion

Weather-related delays on the North Sydney-Port aux Basques run had an average economic loss of $3.5 million per year. The corresponding losses for 2003 and 2004 were $2.1 million and $4.9 million, respectively. These weather-related delays involved 6,567 passengers and 2,655 commercial vehicles in 2003. Weather-related delays were more frequent in 2004 than in 2003. Specifically, in 2004 there were 10,606 passengers and 4,258 commercial vehicles that experienced delays on the Port aux Basques-North Sydney run. Moreover, the number of hours of weather related delays in 2004 were nearly double those of 2003: 1,377 hours in 2004 versus 660 hours in 2003.
7. Summary and Discussion

The southwest coast of Newfoundland has been subjected to many significant storms resulting in property destruction. The storm of January 2000 is the most recent event causing significant damage to Channel-Port aux Basques. Analysis of this event has served as a model for predicting the impact of future storms. The coastline of southwestern Newfoundland has been subject to at least 5 storm surge events since January 2000, including those resulting from Hurricane Gustav (12 September 2002) and Hurricane Frances (2 September 2004).

The estimated economic damage from the January 2000 event exceeded $1 million. However, study of other flooding events in Newfoundland indicates that actual costs were more than twice the reported figures in all instances. Applying a similar standard to Port aux Basques would suggest that the actual financial impact of the 21-22 January 2000 storm surge event would approach $ 3 million. This figure does not account for any losses resulting in disruption to transportation between Port aux Basques and the remainder of Newfoundland.

The effectiveness of any particular storm at a location depends upon the angle of wave attack, the number of previous events during the season, and other local factors. Adjacent beaches can exhibit very different responses to a particular storm, as was evident on southwestern Newfoundland beaches impacted by Hurricanes Gustav (2002) and Frances (2004).

Although the relationship between changes in hurricane frequency and magnitude, and increases in air temperature or sea surface temperature, is not clear at present, and consensus does not exist, it is apparent that the North Atlantic is currently undergoing a period of increased hurricane activity. Planning emergency response measures to cope with the impact of storm surges associated with either hurricanes or mid-latitude cyclones is necessary. Exercises such as “Operation Dolphin”, conducted at Channel- Port aux Basques in June 2006 (Seguin et al., 2006) are vital planning and preparatory tools.

Tsunamis are the products of seismic activity, and are not related to climate. However, their potential impact on the southwest Newfoundland coastline is similar to that for storm surges. The frequency of tsunami events cannot be assessed at present.
Sea level is currently rising at Port aux Basques at ca. 3.3 mm/a. Rising sea level will allow successive storm surges to rise higher and penetrate further inland. The shoreline at Port aux Basques Harbour is not sensitive to coastal erosion resulting from sea level rise. Coastal erosion is occurring along dune-backed sandy shorelines, such as those at JT Cheeseman and Sandbanks Provincial Parks.

There is no clear net change in tidal regime for the period of tidal records for Port aux Basques (1935-present). There is, however, an indication of the de-tided residual increasing over time (approximately 10 cm from 1959 to 2005). Unfortunately, this increase cannot be accurately interpreted since the data set is highly fragmented, but some of the increasing trend is likely due to relative sea level rise in the area.

There is a clear seasonal trend in mean water level. The mean and variance is higher during the fall and winter than in the spring and summer. The atmospheric pressure exhibits a clear seasonal trend. The pressure is lower with a higher variability during the late fall and winter.

There is no obvious correlation between the NAO and the tidal constituents, or storm surge activity (neither by frequency in terms of number of events or duration nor by maximum surge height). In contrast to the situation in eastern Newfoundland, considering the North Atlantic Oscillation is not an effective predictor or explanation for surge activity at Port aux Basques. The annual number of events that exceed 60 cm shows no real trend and there has been little change in the annual maximum storm surge elevation.

The maximum water level for extreme events, such as the January 2000 storm, that have been excluded from the data record can be roughly estimated using basic statistical correlations based on the recorded meteorological conditions along with the records of other previous storm/surge events. However, the lack of tide gauge data from the period surrounding the January 2000 storm represents a serious limitation on interpretation of this event, and on the ability to recognize long-term trends and predict the pattern of future storm surge events. Tidal gauge networks require adequate maintenance and associated funding, in order for significant and productive research to continue and for public safety.
Historically, Wreckhouse Events have been known and respected since the initial railway construction period. At present, it is not possible to assess if any change has occurred in the frequency of Wreckhouse Events, as judged from resultant delays to transportation, over the historical record. The available archival data appears to be inadequate for such an assessment.

The data show considerable inter-annual and inter-decadal variability in the frequency of Wreckhouse events and the maximum sustained wind expected. Differences in analysis and treatment of the same set of meteorological data can produce seemingly different results. The variations in results reflect the relatively short length of the data set available, and the difficulties in assessing the data.

Figures 7.1 and 7.2 illustrate data generated during preliminary analysis, and presented in 2005. The data include the percentage of Wreckhouse winds in excess of 57 km/h, a critical value for the interruption of transportation (Figure 7.1), and the inferred peak velocity for Wreckhouse winds (Figure 7.2). Both data sets suggest a trend of increasing Wreckhouse events, based on analysis of data from ca. 1967 to 2004.

![Percentage of Wreckhouse easterly winds in excess of 57 km/h.](image)

Figure 7.1 Percentage of Wreckhouse easterly winds in excess of 57 km/h. Graph prepared by Dale Foote and Dermot Kearney from Environment Canada data, 2005.
However, subsequent analysis, reported in chapter 5 of this report and including data from 2005, suggests that the activity of Wreckhouse winds may be much more variable. Figures 7.3 and 7.4 suggest that there is no apparent long-term trend in the Wreckhouse wind data, with peak wind velocities (Figure 7.3) and total yearly hours (Figure 7.4).
Figure 7.3 Inferred Wreckhouse Peak wind velocities, three year averages, 1966-2004.

Figure 7.4 Wreckhouse Event total yearly hours
The available data thus are subject to different interpretations. The increased wind velocities documented at Port aux Basques, as discussed in chapter 5, indicate that wind velocities at Wreckhouse would also increase, as these two phenomena are linked meteorologically. However, increases in *mean* wind velocity at Port aux Basques may not translate directly into increases in *peak* wind velocity at Wreckhouse.

At present, it is prudent to conclude that Wreckhouse events will not become less frequent in the future, and could become more frequent. The problems of data analysis also strongly indicate that more detailed, locally specific investigations are necessary. They further highlight the absence of reliable (or any) archival data, which could be used to assess a longer-term change in the number and severity of events (replacing a 40-year recording period, with gaps, with a longer time series). The problem is similar to the difficulties in interpreting the tidal and storm surge record, which is also relatively short and contains significant gaps.

Assessment of climate change and variation is contingent on reliable, complete data recorded over long periods of time. Unfortunately, missing data severely hinders interpretation of climate patterns for both Port aux Basques and Wreckhouse.

The most recent cost estimates of disruption to highway traffic, summarized by ADI Limited (1994), suggest that accidents cost ca. $236,000 annually, and delays cost a further $1.9 million (as measured in 2006 dollars). Thus, the cost of Wreckhouse Events to the provincial economy is in excess of $2.1 million annually. This figure only includes insured losses and delays, and does not include delays or damage to smaller, non-commercial vehicles, or costs involved with response to accidents or road maintenance and repair.

Analysis of trends of mean wind speed indicate a statistically significant increasing trend at Port aux Basques, combined with statistically significant decreasing trends for Burgeo and Sydney Airport. These differences reflect the influence of local topography on wind velocity. They also indicate a necessity for detailed local measurements at several sites, in order both to establish long-term regional trends and for local forecasting in aid of marine navigation.
There is high interannual variability in westerly wind disruption to marine transportation. Although easterly winds are of concern for the Wreckhouse area, it is the westerlies that have the greatest potential to produce stormy conditions in Cabot Strait.

Weather-related delays on the North Sydney-Port aux Basques run had an average economic loss of $3.5 million per year. The corresponding losses for 2003 and 2004 were $2.1 million and $4.9 million, respectively. These weather-related delays involved 6,567 passengers and 2,655 commercial vehicles in 2003. Weather-related delays were more frequent in 2004 than in 2003. Specifically, in 2004 there were 10,606 passengers and 4,258 commercial vehicles that experienced delays on the Port aux Basques-North Sydney run. Moreover, the number of hours of weather related delays in 2004 were nearly double those of 2003: 1,377 hours in 2004 versus 660 hours in 2003.

Adding the costs for transportation delays related to storm and wind activity along the route from Channel-Port aux Basques through Wreckhouse suggests an average loss of $5.6 million annually. These costs represent the current losses due to storms, surges, and winds, and do not consider the potential of increased future losses due either to changes in the condition of the infrastructure or to any changes in climate. The available data suggest that the climate regime, as it currently exists, is sufficient to have significant economic impact to transportation in Southwestern Newfoundland.
8. References


Cardone, VJ, Jensen, RE, Resio DT, Swail VR, and Cox AT, 1995. Evaluation of Contemporary Ocean Wave Models in Rare Extreme Events: The Halloween Storm of


Shaw, J., 2006. Adaptation to rising sea level in the Bras d´Or Lakes, Canada’s largest inland sea. Canadian Climate Impacts and Adaptations Directorate, report.


### 9. Appendices

**Appendix A**

**Station Histories**  
**STEPHENVILLE - 48 32'58 33''**

<table>
<thead>
<tr>
<th>DATE</th>
<th>ANEMOMETER ELEVATION/ HEIGHT</th>
<th>ANEMOMETER TYPE</th>
<th>WIND RECORDER TYPE</th>
<th>MANNED/AUTO</th>
<th>WIND SPEED AVERAGING PERIOD (MINUTES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan/53</td>
<td>Unknown/ 3.96m</td>
<td>AN-GMQ-11</td>
<td>UNKNOWN</td>
<td>MANNED</td>
<td>?</td>
</tr>
<tr>
<td>June/66</td>
<td>7.92m/ 6m</td>
<td>U2A</td>
<td>MONRO</td>
<td>MANNED</td>
<td>1</td>
</tr>
<tr>
<td>Sept/66</td>
<td>7.92m/ 10.0m</td>
<td>U2A</td>
<td>MONRO</td>
<td>MANNED</td>
<td>1</td>
</tr>
<tr>
<td>?/1980</td>
<td>7.92m/ 10.0m</td>
<td>78D</td>
<td>ELECTRONIC</td>
<td>MANNED</td>
<td>2</td>
</tr>
</tbody>
</table>

**BURGEO- 47 37'57 37''**

<table>
<thead>
<tr>
<th>DATE</th>
<th>ANEMOMETER ELEVATION/ HEIGHT</th>
<th>ANEMOMETER TYPE</th>
<th>WIND RECORDER TYPE</th>
<th>MANNED/AUTO</th>
<th>WIND SPEED AVERAGING PERIOD (MINUTES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>July/66</td>
<td>22.73m/ 10.0m</td>
<td>45B</td>
<td>WIND RUN</td>
<td>MANNED</td>
<td>60</td>
</tr>
<tr>
<td>Sept/69</td>
<td>22.73m/ 10.0m</td>
<td>U2A</td>
<td>MONRO</td>
<td>MANNED</td>
<td>10</td>
</tr>
<tr>
<td>Oct 02/91</td>
<td>22.73m/ 10.0m</td>
<td>U2A</td>
<td>MONRO</td>
<td>MANNED and AUTO8</td>
<td>10</td>
</tr>
<tr>
<td>July 31/95</td>
<td>22.73m/ 10.0m</td>
<td>U2A</td>
<td>N/A</td>
<td>AUTO8</td>
<td>10</td>
</tr>
</tbody>
</table>

**SYDNEY - 46 10'60 03''**

<table>
<thead>
<tr>
<th>DATE</th>
<th>ANEMOMETER ELEVATION/ HEIGHT</th>
<th>ANEMOMETER TYPE</th>
<th>WIND RECORDER TYPE</th>
<th>MANNED/AUTO</th>
<th>WIND SPEED AVERAGING PERIOD (MINUTES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>June/53</td>
<td>55.5m/ 19.5m</td>
<td>45B</td>
<td>WIND RUN</td>
<td>MANNED</td>
<td>60</td>
</tr>
<tr>
<td>August/55</td>
<td>55.5m/ 19.8m</td>
<td>45B</td>
<td>WIND RUN</td>
<td>MANNED</td>
<td>60</td>
</tr>
<tr>
<td>November/59</td>
<td>55.5m/ 19.5m</td>
<td>U2A</td>
<td>MONRO</td>
<td>MANNED</td>
<td>?</td>
</tr>
<tr>
<td>February/65</td>
<td>55.5m/ 16.4m</td>
<td>45B</td>
<td>WIND RUN</td>
<td>MANNED</td>
<td>60</td>
</tr>
<tr>
<td>July/66</td>
<td>55.5m/ 10.0m</td>
<td>U2A</td>
<td>MONRO</td>
<td>MANNED</td>
<td>?</td>
</tr>
<tr>
<td>August/68</td>
<td>55.5m/ 10.0m</td>
<td>U2A</td>
<td>MONRO</td>
<td>MANNED</td>
<td>1</td>
</tr>
<tr>
<td>June/72</td>
<td>55.5m/ 10.0m</td>
<td>U2A/R</td>
<td>MONRO</td>
<td>MANNED</td>
<td>1</td>
</tr>
<tr>
<td>?/1980</td>
<td>55.5m/ 10.0m</td>
<td>U2A/R</td>
<td>MONRO</td>
<td>MANNED</td>
<td>2</td>
</tr>
<tr>
<td>November/96</td>
<td>55.5m/ 10.0m</td>
<td>78D</td>
<td>ELECTRONIC</td>
<td>MANNED</td>
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### PORT AUX BASQUES

<table>
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<th>SITE DESCRIPTION</th>
<th>DATE</th>
<th>ANEMOMETER ELEVATION/HEIGHT</th>
<th>ANEMOMETER TYPE</th>
<th>WIND DISPLAY</th>
<th>WIND SPEED AVERAGING PERIOD (MINUTES)</th>
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<tbody>
<tr>
<td>Telegraph and Cable Office</td>
<td>1929</td>
<td>45.5m/6.1m</td>
<td>?</td>
<td>?</td>
<td>?</td>
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<tr>
<td>Loran Transmitting Station</td>
<td>1955</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Mouse Island 47 34'/59 10'</td>
<td>June/66</td>
<td>17.0m/13m</td>
<td>U2A</td>
<td>MONRO</td>
<td>10</td>
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<tr>
<td>800m NNE of previous location</td>
<td>August/83</td>
<td>49m/10m</td>
<td>U2A</td>
<td>DIAL</td>
<td>10</td>
</tr>
<tr>
<td>Manned/Auto (no change in location)</td>
<td>October/91</td>
<td>49m/10m</td>
<td>U2A</td>
<td>DIAL</td>
<td>10</td>
</tr>
<tr>
<td>AWOS (no change in location)</td>
<td>Spring/98</td>
<td>49m/10m</td>
<td>78D</td>
<td>ELECTRONIC</td>
<td>10</td>
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### ST. ANDREWS-47 46'/59 19'

<table>
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<th>DATE</th>
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<th>ANEMOMETER TYPE</th>
<th>WIND RECORDER TYPE</th>
<th>MANNED/AUTO</th>
<th>WIND SPEED AVERAGING PERIOD (MINUTES)</th>
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<tbody>
<tr>
<td>1953-May 1966</td>
<td>21.0/1.83m</td>
<td>45B</td>
<td>NONE</td>
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<td>60</td>
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### WRECKHOUSE-47 42'/59 18'

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<th>ANEMOMETER TYPE</th>
<th>WIND RECORDER TYPE</th>
<th>MANNED/AUTO</th>
<th>WIND SPEED AVERAGING PERIOD (MINUTES)</th>
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<tbody>
<tr>
<td>Jan 2000</td>
<td>31.7m/10m</td>
<td>R.M Young</td>
<td>NONE</td>
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</table>
Appendix B: Seasonal Graphs

Burgeo Seasonal Wind Speed Categories
DJF 1970-2004

Year

% Occurrence

% < 19
% Strong
% Gale
% Storm

Burgeo Seasonal Wind Speed Categories
MAM 1970-2004

Year

% Occurrence

% < 19
% Strong
% Gale
% Storm
Stephenville Airport Seasonal Wind Speed Categories

DJF 1967-2004

Year

% Occurrence

% < 19
% Strong
% Gale
% Storm

MAM 1967-2004

Year

% Occurrence

% < 19
% Strong
% Gale
% Storm
Sydney Airport Seasonal Wind Speed Categories
JJA 1969-2004

% Occurrence

% < 19
% Strong
% Gale
% Storm

Year

Appendix C: Wind Rose Diagrams

Joint Frequency Distribution
Burgeo, NL (1966-2004) February

Wind flow is FROM the directions shown.
Rings drawn at 5% intervals.
Calms included at center.

Wind Speed (Kilometers Per Hour)

Joint Frequency Distribution
Burgeo, NL (1966-2004) March

Wind flow is FROM the directions shown.
Rings drawn at 5% intervals.
Calms included at center.

Wind Speed (Kilometers Per Hour)

Joint Frequency Distribution
Burgeo, NL (1966-2004) April

Wind flow is FROM the directions shown.
Rings drawn at 5% intervals.
Calms included at center.

Wind Speed (Kilometers Per Hour)
No observations were missing.
Wind flow is FROM the directions shown.
Rings drawn at 5% intervals.
Calms included at center.

Wind Speed (Kilometers Per Hour)

1 11 21 31 41 51
Joint Frequency Distribution
Burgeo, NL (1966-2004) September

No observations were missing.
Wind flow is FROM the directions shown.
Rings drawn at 5% intervals.
Calms included at center.

Wind Speed (Kilometers Per Hour)

Joint Frequency Distribution
Burgeo, NL (1966-2004) October

No observations were missing.
Wind flow is FROM the directions shown.
Rings drawn at 5% intervals.
Calms included at center.

Wind Speed (Kilometers Per Hour)

Joint Frequency Distribution
Burgeo, NL (1966-2004) November

No observations were missing.
Wind flow is FROM the directions shown.
Rings drawn at 5% intervals.
Calms included at center.

Wind Speed (Kilometers Per Hour)

Joint Frequency Distribution
Burgeo, NL (1966-2004) December

No observations were missing.
Wind flow is FROM the directions shown.
Rings drawn at 5% intervals.
Calms included at center.

Wind Speed (Kilometers Per Hour)
No observations were missing.

Wind flow is FROM the directions shown.

Rings drawn at 5% intervals.

Calms included at center.

Wind Speed (kmh)
Joint Frequency Distribution
Port aux Basques, NL (1966-2004) May

Wind flow is FROM the directions shown. Rings drawn at 10% intervals. Calms included at center.

Wind Speed (kmh)
1 11 21 31 41 51

Joint Frequency Distribution
Port aux Basques, NL (1966-2004) June

Wind flow is FROM the directions shown. Rings drawn at 10% intervals. Calms included at center.

Wind Speed (kmh)
1 11 21 31 41 51

Joint Frequency Distribution
Port aux Basques, NL (1966-2004) July

Wind flow is FROM the directions shown. Rings drawn at 10% intervals. Calms included at center.

Wind Speed (kmh)
1 11 21 31 41 51

Joint Frequency Distribution
Port aux Basques, NL (1966-2004) August

Wind flow is FROM the directions shown. Rings drawn at 10% intervals. Calms included at center.

Wind Speed (kmh)
1 11 21 31 41 51

No observations were missing.

Joint Frequency Distribution
Stephenville A, NL (1967-2004) January

Wind Speed (kmh)

Joint Frequency Distribution
Stephenville A, NL (1967-2004) February

Wind Speed (kmh)

Joint Frequency Distribution

Wind Speed (kmh)

Joint Frequency Distribution
Stephenville A, NL (1967-2004) April

Wind Speed (kmh)
No observations were missing.

Wind flow is FROM the directions shown.

Rings drawn at 5% intervals.

Calms included at center.

Wind Speed (kmh)
Joint Frequency Distribution
Stephenville A, NL (1967-2004) September

No observations were missing.
Wind flow is FROM the directions shown.
Rings drawn at 5% intervals.
Calms included at center.

Wind Speed (kmh)
1 11 21 31 41 51

Joint Frequency Distribution
Stephenville A, NL (1967-2004) October

No observations were missing.
Wind flow is FROM the directions shown.
Rings drawn at 5% intervals.
Calms included at center.

Wind Speed (kmh)
1 11 21 31 41 51

Joint Frequency Distribution
Stephenville A, NL (1967-2004) November

No observations were missing.
Wind flow is FROM the directions shown.
Rings drawn at 5% intervals.
Calms included at center.

Wind Speed (kmh)
1 11 21 31 41 51

Joint Frequency Distribution
Stephenville A, NL (1967-2004) December

No observations were missing.
Wind flow is FROM the directions shown.
Rings drawn at 5% intervals.
Calms included at center.

Wind Speed (kmh)
1 11 21 31 41 51
No observations were missing.
Wind flow is FROM the directions shown.
Rings drawn at 5% intervals.
Calms included at center.

Wind Speed (kmh)
1 11 21 31 41 51
No observations were missing.

Wind flow is FROM the directions shown.
Rings drawn at 5% intervals.
Calms included at center.

<table>
<thead>
<tr>
<th>Wind Speed (kmh)</th>
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<tbody>
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</tr>
<tr>
<td>3.04</td>
</tr>
<tr>
<td>3.12</td>
</tr>
<tr>
<td>6.36</td>
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<table>
<thead>
<tr>
<th>Wind Speed (kmh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>4.03</td>
</tr>
<tr>
<td>2.69</td>
</tr>
<tr>
<td>8.06</td>
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<table>
<thead>
<tr>
<th>Wind Speed (kmh)</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>4.11</td>
</tr>
<tr>
<td>2.18</td>
</tr>
<tr>
<td>9.71</td>
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<table>
<thead>
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<th>Wind Speed (kmh)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>4.64</td>
</tr>
<tr>
<td>2.11</td>
</tr>
<tr>
<td>11.34</td>
</tr>
</tbody>
</table>
No observations were missing.
Wind flow is FROM the directions shown.
Rings drawn at 5% intervals.
Calms included at center.

Wind Speed (kmh)
1 11 21 31 41 51