Storm Surges

Storm surges can occur on both marine and lake shorelines and can cause significant coastal flooding. A storm surge is defined as the difference between predicted tide (or, for lakes, the typical lake level) and the measured high water level. Predicted tide is also known as astronomical tide because it is caused by the relative motions of the Sun, Moon and Earth, among other factors. Water level measured using a tide gauge incorporates both astronomical tide (or lake level) and meteorological impacts on water level, such as wind speed and direction, and air pressure. A storm surge is said to occur when water level exceeds the predicted tide or lake level. As the name implies, storm surges occur during storms when strong winds blow onshore, pushing water against the coast. Another factor is that low air pressure during storms further raises water levels at the coast. The underwater slope of the coast also influences how high a surge can grow locally (for example, surges are higher on gently sloping coasts than on steep coasts).

Storm surges can occur at any tide level but are most damaging when they occur at high tide. A storm surge occurring at high tide can cause coastal flooding well inland from the shoreline, cutting off road access to communities and emergency services, pollution of drinking water sources, and even death. Low-lying areas are most prone to flooding. The high waves that also tend to occur during storm surges can cause severe erosion and damage to structures at the shoreline, such as wharves and houses. Even more damage can result if ice is present: ice being pushed onshore by waves and at abnormally high water levels presents a significant hazard along much of Canada’s shoreline.

The ocean shoreline of Canada is approximately 243 000 kilometres long, and includes the Pacific, Atlantic, and Arctic coasts. Not counted in this total are the shorelines of large lakes in Canada, such as the Great Lakes and Lake Winnipeg, which include a great length of shoreline. Storm surges are known to occur on all four coasts, but the details of the hazard are poorly known in most areas.

One issue that affects communities differently and is important to incorporate into local storm-surge hazard management planning is the impact of rising sea level. Many coastal communities in Canada are experiencing sea-level rise, and one impact of changing climate is the potential for accelerated sea-level rise. This is important for storm-surge management because it means that over a 50 year planning time frame, for example, storm surges will result in higher water levels and cause more severe flooding. The future rate of sea-level rise is different for different communities because it depends upon land subsidence or uplift rates. In subsiding areas, sea-level rise could be as much as 70 centimetres over the next 100 years.

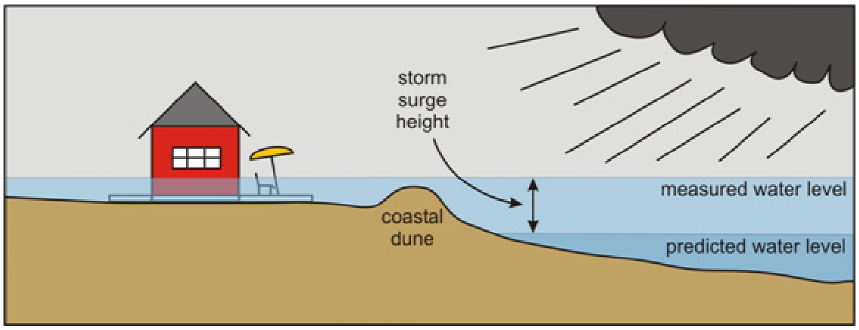

Figure 1. Height of a storm surge during onshore winds when measured water levels are higher than predicted. In this figure, the storm surge raises the predicted water level high enough to overtop a small coastal dune and cause flooding, which impacts a dwelling inland. Not shown are the storm waves that, when superimposed on the high water levels during the surge, would cause additional damage to the dwelling and also the small protective coastal dune.
Source: Geological Survey of Canada

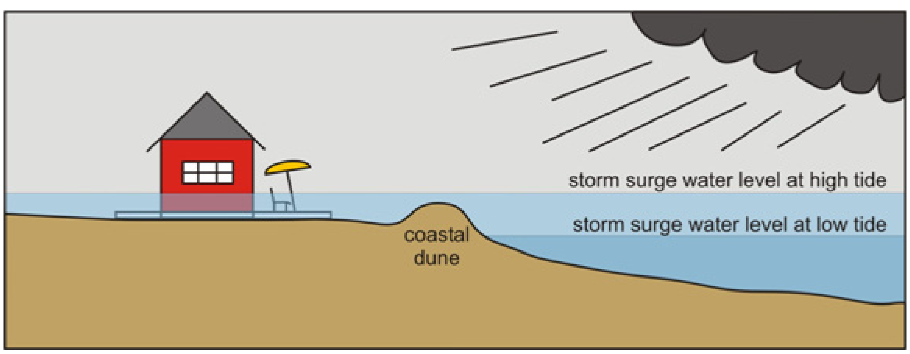

Figure 2. Tide is important in controlling how much flooding can occur during a storm surge. This figure shows a surge that would not overtop the dune at low tide, so flooding would not occur, and the same surge at high tide, which would result in significant flooding and damage to a dwelling inland.
Source: Geological Survey of Canada

Table 1. Impact of Storm Surges

Date	Location	Dollars and Death Information
October 2003	Halifax and other parts of Nova Scotia and Prince Edward Island	$200 million (mostly wind damage)
January 2000	Particularly damaging at Charlottetown (see case study below)	$20 million
September 1985	Long Point, Lake Erie	40 cottages destroyed
October 1983	Cape Breton	$2.7 million, 36 vessels destroyed
December 1982	Vancouver, Victoria	Some destruction of property
September 1970	Mackenzie Delta–Tuktoyaktuk (see case study below)	2 fatalities
December 1951	Newfoundland (south coast)	600 evacuated
October 1869	Bay of Fundy	Estimated 30 fatalities

Sources: Selected storms from Public Safety Canada Web site, described by local residents, or taken from scientific publications.

Case Studies

Tuktoyaktuk

On September 14, 1970, a severe storm tracking eastward into the Beaufort Sea generated a storm surge that affected the Yukon coast, the Mackenzie Delta and the coastal hamlet of Tuktoyaktuk in the Northwest Territories. The storm brought wind speeds up to 92 kilometres per hour from the northwest and wave heights up to 4.2 metres. The Tuktoyaktuk tide gauge was not operating at the time, so the exact surge height is unknown. From driftwood strandlines, the water level is estimated to have reached 2.4 metres above Chart Datum (in Canada, Chart Datum is defined as the lower low water level reached during large tides — essentially the water level during very low tides). This storm caused the record high water level at Tuktoyaktuk.

This event is significant because it contributed to the death of two technicians who were performing maintenance on a navigation installation on Tent Island in the Mackenzie Delta. The surge covered the entire island, which is less than 1 metre above water level, forcing the surveyors to climb a navigation tower, where they succumbed to exposure.

Sea-level is currently rising at Tuktoyaktuk at 3.5 millimetres per year. Climate models suggest an acceleration in the rate of sea-level rise, possibly resulting in 0.31 metre rise by 2050 and 0.76 metre by 2100. Addition of these levels to the water level reached during the 1970 storm indicates that flooding to 2.7 metres and 3.2 metres above Chart Datum will occur should a storm like the 1970 storm occur in 2050 and 2100, respectively. The 2.4 metre water level reached in 1970 has a return period of approximately 30 years. By 2100 flooding to 2.4 metres above Chart Datum is expected to occur annually.

Figure 3. Driftwood deposited well above sea level in a lakebed near Tuktoyaktuk during the 1970 storm surge
Source: Photograph by Gavin Manson, Geological Survey of Canada

Figure 4. Tuktoyaktuk during a mild storm and a small surge
Source: Photograph by Gavin Manson, Geological Survey of Canada

Charlottetown

On January 21, 2000, an intense storm travelling northward up the east coast of the United States passed over Prince Edward Island, approximately 55 kilometres east of Charlottetown. Wind speeds in the southern Gulf of St. Lawrence exceeded 70 kilometres per hour from the northeast, and a surge 1.36 metres high coincided with high tide and caused a new record water level in Charlottetown of 4.23 metres above Chart Datum.

Significant flooding damage occurred at Charlottetown and other communities in Prince Edward Island. Infrastructure damaged during the surge at Charlottetown included wharves lining the harbour, a power-generating station, a lighthouse, numerous gas stations, and many municipal and private properties. Approximately 460 properties were either flooded or at risk of flooding, with a total assessed value of 1.7 million. Damage was estimated at $20 million for all areas affected by this surge.

Sea level is rising at Charlottetown at a rate of 3.2 millimetres per year. When climate change projections are taken into account, 0.7 metre of sea-level rise is expected by 2100 which would raise the flood level due to the 2000 storm to 4.93 metres above Chart Datum. Such a storm surge scenario would increase the number of properties at risk to 685, with an assessed value of $2.02 million.

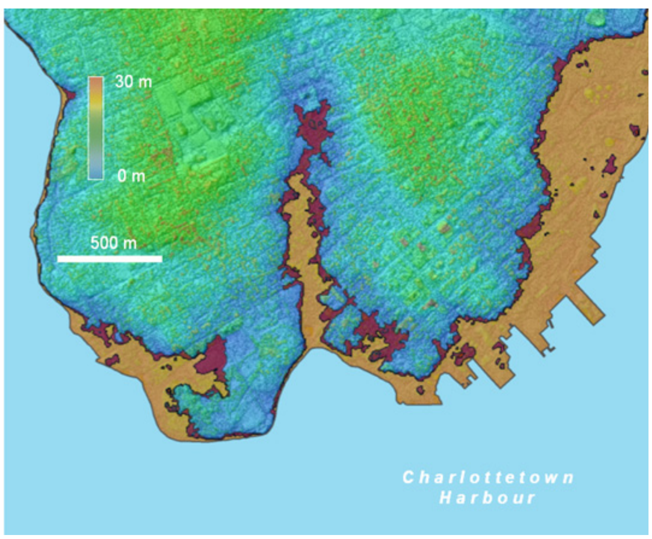

Figure 5. Digital Elevation Model of Charlottetown. This digital elevation model of Charlottetown shows flooding during the January 2000 storm (orange) and a projection of additional flooding should the same storm occur in 2100 after 0.7 metre of sea-level rise (red). Current sea level in light blue shows the usual shoreline and wharves of Charlottetown.
Source: Geological Survey of Canada

Figure 6. Damage to a Lighthouse in Charlottetown Harbour. The storm surge raised the water level above the foundation of the lighthouse and wind drove sea ice through the lower wooden wall and shifted the entire structure off its foundation. A sheet of ice can be seen protruding from the wall.
Source: Photograph by Gavin Manson, Geological Survey of Canada

Mitigation/Vulnerability

When a storm approaching the coast is expected to result in a surge, the Meteorological Service of Canada issues a storm-surge warning on the Web, through their telephone and Weatheradio services, and also usually through local news and weather forecasts. In extreme cases, these warnings may be accompanied by recommendations from local emergency organizations to evacuate low-lying areas. Protect your family by monitoring approaching storms and watch for storm-surge warnings. Learn if you live in an area prone to storm surges. Have a plan to regain contact with family members in case of evacuation and know your safe evacuation routes. A safety kit with food, fresh water, flashlight, first aid kit and a battery-powered radio (with extra batteries) is recommended. The Public Safety Canada Web site 'Is your family prepared?' (http://www.getprepared.gc.ca/index-eng.aspx) has excellent advice on what to include in both an emergency plan and an emergency kit. These can be put to good use in any natural disaster or emergency.

At the community level, planners and municipal leaders can prepare for storm surges by developing an emergency plan that is co-ordinated and implemented during a surge by a designated team. In Canada, provincial emergency management organizations can assist in developing emergency plans and training staff. Planners can determine which areas in a community are most vulnerable and if emergency response staff will be able to reach these areas during a storm surge. Preparation of local surge hazard maps and simulation exercises may be useful in making these determinations. Storm-surge damage can be mitigated in advance by reinforcing or protecting vital infrastructure, but consideration must be given to the cost of protection versus relocation. Should infrastructure damage occurs during a surge, planners and municipal leaders must then decide whether the infrastructure should be rebuilt in the same location or in an area of lower vulnerability. These decisions should consider that, in areas of rising sea level, the extent of vulnerable areas at risk of flooding will increase. In areas where flooding has occurred in the past, future depth of flooding, and therefore damage, will also increase with sea-level rise.

Definition of underlined term

Chart Datum: Chart Datum is the plane of vertical reference to which all charted depths and drying heights are related. In non-tidal waters, it is also the vertical datum for elevations and clearances. It is chosen to show the least depth of water found in any place under "normal" meteorological conditions; it shall be a plane so low that the water level will seldom fall below it. The surface of the chart datum will vary from place to place with the range of tide or, in non-tidal waters, with the slope of the river at low stage. In non-tidal lakes, the chart datum is normally a single level surface over the whole lake. (Source: Hydrographic Dictionary, International Hydrographic Organisation; and the Canadian Tidal Manual, Canadian Hydrographic Service, Fisheries and Ocean Canada)