Tides

Lesson Overview:
This lesson details characteristics of tides and their significance to New Brunswick. Teachers can utilize the material as they see fit through a variety of approaches, strategies and methods; student activities, projects, assignments and presentations.

Grade Level:
9-12

Time Required:
Two one-hour classes

Curriculum Connection (Province and course):
New Brunswick: Physical Geography 110 and World Geography 120; and AP and IB Programs
This lesson could also be applied or modified to any geography or science curriculum in Canada

Atlantic Provinces Education Foundation Curriculum for Social Studies:
General Curriculum Outcomes:
Individuals, Societies and Economic Decisions
Students will be expected to demonstrate the ability to make responsible economic decisions as individuals and as members of society.

Interdependence
Students will be expected to demonstrate an understanding of the interdependent relationship among individuals, societies and the environment—locally, nationally and globally—and the implications for a sustainable future.

People, Place and Environment
Students will be expected to demonstrate an understanding of the interactions among people, places and the environment.

Link to Canadian National Geography Standards:
Essential Element #1: The World in Spatial Terms
  - Map, globe and atlas use
Ocean Standard #1: The World in Spatial Terms
  - Location and patterns of ocean characteristics:
Study of the tidal patterns and currents involves linkage to their spatial position, involving usage of maps/globe/atlas. Conic projections are appropriate here. Location of coastal communities with respect to the tidal currents, and allocation of marine resources can also be discussed.

### Essential Element #2: Places and Regions
- Physical and human processes shape place and regions
- Interdependence of places and regions
- Critical issues and problems of places and regions
- Regional analysis of geographic issues and questions

### Ocean Standard #2: Places and Regions
- Physical and human processes that shape the ocean and coasts
- Interdependence of land areas and the ocean

The tide is the dominant physical factor shaping the coastline of the Bay of Fundy, and plays a significant role along the coastline of the Gulf of St. Lawrence. Tides have influenced life in the coastal communities of New Brunswick in many respects. Study of tides can involve analyses at local (community), regional (Fundy, Gulf Coast), Atlantic Canada and Northern North Atlantic scales.

### Essential Element #3: Physical Systems
- Components of Earth’s physical system
- Global ocean and atmospheric systems

### Ocean Standard #3: Physical Systems
- Processes of ocean physical systems

Tides are a key component of the physical environment of the Maritimes. Tidal activity contributes to the differences in biogeography between the Bay of Fundy and the Gulf of St. Lawrence.

### Essential Element #4: Human Systems
- Population characteristics in world regions, country, and regions within countries
- Demographic transition

### Ocean Standard #4: Human Systems
- The role of oceans in economic development

Tides influence the coastal communities of New Brunswick. Its influences on fishing and transportation are profound locally. Its contribution to tourism, especially along the Bay of Fundy, illustrates the concept of Global Economic Interdependence.
Essential Element #5: Environment and Society:
- Global effects of human modification of the physical environment
- Global effects on the human environment by changes in the physical environment
- Use and sustainability of resources
- Environmental issues

Ocean Standard #5: Environment and Society
- Ocean policies and regulations
- Changes in world ocean resources and distribution over time

The significance of the tide in controlling shipping times and fishing efforts demonstrates the effect that the physical environment has on the human environment.

Geographic Skills:
Uses of Geography: Study of the tides along the coasts of New Brunswick represents an example of the value of a regional analysis in the context of the North Atlantic region as a whole.

Geographic Skill #1: Asking Geographic Questions
- Plan and organize a geographic research project

Geographic Skill #2: Acquiring Geographic Information
- Systematically locate and gather geographic information from a variety of primary and secondary sources

Geographic Skill #3: Organizing Geographic Information
- Select and design appropriate forms of maps to organize geographic information
- Select and design appropriate forms of graphs, diagrams, tables and charts to organize geographic information
- Use a variety of media to develop and organize integrated summaries of geographic information

Geographic Skill #4: Analyzing Geographic information
- Make inferences and draw conclusions from maps and other geographic representations

Geographic Skill #5: Answering Geographic Questions
- Formulate valid generalizations from the results of various kinds of geographic inquiry

Study of the tides of the New Brunswick coast involves asking geographic questions on a number of levels, from the purely descriptive and locational, through to questions of marine processes, effects of human activity (e.g. fisheries, transportation, tourism), to questions concerning human and...
community response to and interaction with the natural environment. Answering the questions will require acquisition, organization and assessment of geographical information, including that presented in this lesson as well as information obtained from other sources.

**Additional Resources, Materials and Equipment Required:**

*Powerpoint* presentation (attached)- It is suggested to print notes regarding details of pictures in PP presentation.

Diagrams 1 and 2 (attached)

Computer and Internet access for map research/creation:
- [www.ccge.org/english/Mapmaker](http://www.ccge.org/english/Mapmaker)
- [www.atlas.gc.ca](http://www.atlas.gc.ca)

Globe, maps, atlases and other reference materials: None are required, aside from atlases/maps normally used in class. The powerpoint presentation attached here can be used as well.

Additional resources could be incorporated if it is desired to expand on any of the points in the lesson plan as listed here. Additional resources could include:

- Detailed map of New Brunswick
- Detailed tidal charts
- Bathymetric charts

**Main Objective:**

- Understand the physical characteristics of tidal activity.
- Understand the reasons for the differences in tidal activity between the coasts of the Bay of Fundy and the Gulf of St. Lawrence.
- Understand the interactions between the tide and other elements of the physical environment.
- Understand the socio-economic and cultural significance of tidal activity in New Brunswick.

**Learning Outcomes:**

- In addition to fulfilling the objectives above, students can apply the same analytical techniques to the understanding of the characteristics, impact, influences and significance of tidal activity in another location.
- Understanding the interplay between biophysical and socio-economic geographical concepts.
- Understanding that the concepts presented in “Oceans for Life” can be applied to any marine environment.
The Lesson:

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| The ocean tides result from the gravitational attraction of the Sun and Moon on the surface waters of Earth. The gravitational force between Earth and Sun is expressed as: \( F = G \frac{m_e m_s}{d^2} \)

Where \( G = 6.67 \times 10^{-11} \)

\( m_e = \) mass of Earth (kg)

\( m_s = \) mass of Sun (kg)

\( d = \) distance between Earth and Sun

As the Moon is much closer to Earth than is the Sun, the lunar gravitational effect is stronger and the tidal distortion is aligned towards the Moon, even though Moon has a much smaller mass than Sun | Calculate the gravitational force between Earth and Sun; compare this value with that between Earth and Moon. To do this, you'll need:

\( m_e \)

\( m_s \)

\( m_m \)

Earth-Sun distance

Earth-Moon distance |
Spring and Neap Tides

As the Moon revolves around the Earth once every 28 days, there are two days during this period when the Earth, Sun and Moon are aligned along the same plane. At these times, the gravitational attraction of the Moon and the Sun on the ocean waters of Earth’s surface act in concert. This produces the highest tides of the month, termed ‘spring tides’.

Spring tides are marked by the greatest tidal range—the maximum difference between the elevation of the water surface at high and low tide.

In contrast, there are two days during each month when the Moon and Sun are aligned at 90º to each other, and hence the waters of Earth’s surface are pulled in mutually opposing directions. As the Moon is much closer to Earth than is the Sun, the lunar gravitational effect is stronger and the tidal distortion is aligned towards the Moon.

The magnitude of the distortion, however, is lessened, and thus the smallest tidal ranges of the month occur during these days. These periods are referred to as ‘neap tides’.

See Diagram 1: Spring & Neap Tides

Astronomical Tides

Tidal effects on Earth’s surface are further complicated by irregularities in the orbits of Earth and Moon, and by the Coriolis Force generated on Earth due to its rotation. As the orbits of Moon around Earth, and Earth around Sun, are not perfect ellipses, the irregularities in the orbits cause variations in the amount of gravitational attraction, and hence in the height and timing of the tides.

As well, the declinations of the orbits of the Moon and Earth vary around a horizontal plane, meaning that the maximum gravitational force operates at different positions with respect to the Equator throughout the year.

These astronomical factors operate at time scales varying from approximately once every twelve hours (twice daily, or semi-diurnal), to approximately once daily (diurnal), to approximately once every two weeks (fortnightly). Combinations of these cycles result in the generation of the astronomical tides.

Look at the difference in height between spring and neap tides in your community.

Measure the height of the tide each day.
### Diurnal and semi-diurnal tides

Incoming high tides are referred to as **flood tides**. This does not imply that they result in coastal flooding. Outgoing tides are referred to as **ebb tides**.

Most segments of Earth’s (and Atlantic Canada’s) coastline are subject to two high and two low tides during each rotation of the Earth (all of NL) - **semi-diurnal**.

Earth requires 23 h, 56 min., 4.1 s to rotate, and the astronomical factors do not operate strictly on 12 h and 24 h cycles.

Times for high and low tides at a location change by a few minutes each day.

Semi-diurnal tidal patterns are most common. Semi-diurnal astronomical factors (periods of ~ 12 h), influence gravitational attraction more significantly than do diurnal factors (~ 24 h).

A few regions are subjected to only a single high-low tidal cycle throughout each 24 hour period, and thus have **diurnal** tides (Western Northumberland Strait, including Confederation Bridge; Iles-de-la-Madeleine)

A semi-diurnal tidal pattern where consecutive high tides differ substantially in elevation is termed **mixed**.

### Dynamic and astronomical tides

The configuration of the ocean basins and continents, and the nearshore bathymetry, introduces further complications.

In some coastal areas, such as the Bay of Fundy, this causes significant differences between the timing of the tides that would be predicted from astronomical factors, and the actual **dynamic tides** observed on the shore.

Tidal velocity is directly related to water depth, with tides moving more slowly in shallow waters.

Bathymetric effects result in significant differences in the height of the tide that is observed at individual sites.

As the tide moves through progressively more shallow water, the tidal range, the difference between high and low tides, increases systematically. This is especially notable in areas such as the Bay of Fundy and Bristol Channel, where the bathymetry shallows progressively, and the embayment narrows to form a funnel-like configuration.
Along coastlines such as the Bay of Fundy, there is a substantial difference between the predicted heights of the astronomical tides, and the actual heights of the dynamic tides.

In contrast, the dynamic (actual) heights agree with the predicted (astronomical) heights along the Gulf of St. Lawrence.

**Tidal Range**
Tidal range is defined as the mean difference between the elevations of high and low tide, averaged over a year.

- Microtidal areas have tidal ranges of 2 m or less
- Mesotidal areas have ranges between 2 and 4 m
- Macrotidal areas have ranges in excess of 4 m (up to 15.9 m in the Bay of Fundy).

Tidal ranges along the Gulf of St. Lawrence coast of New Brunswick vary from 1.5 to 3.5 metres. *Salt marshes* are developed in most tidally influenced lagoons and estuaries.

The difference in elevation between each pair of high and low tides varies. During neap tide periods, the total range is at a minimum value: the high tide does not rise as high in elevation, but the low tide does not fall as far.

In contrast, the tidal range is at a maximum during spring tide periods, with the high tide rising to a maximum height and the low tide falling to a minimum low.

**Set-up, and set-down**
Additional variations in tidal range are caused by weather conditions. If a low-pressure system develops along the coastline, water will be driven by the winds towards the shore, causing sea level to rise in response.

When this coincides with high tide, the resultant ‘set-up’ condition causes water levels to rise above the normal high tide position, creating anomalous tidal surges and coastal flooding.

This is a *storm surge*.

During the Saxby Gale of 1869, water levels in the Bay of Fundy rose more than 15 m above the normal high tide position, resulting in flooding of areas up to 30 m above mean sea level. The Tantamar Marshes were flooded, cutting road and rail traffic from New Brunswick to Nova Scotia.

What is the tidal range in your community? In other New Brunswick communities?

Research storm surges in your community. Recent storm surge activity (e.g. January 2000) has affected communities along the Gulf of St Lawrence.

The ‘Groundhog Day Storm’ (2 Feb 1976) affected communities along the Bay of Fundy.
Similar tidal surges and flooding are commonly associated with typhoons in the Bay of Bengal, and with hurricanes in the Caribbean and Central America.

The reverse, set-down, condition can also occur. If a low-pressure system is developed along a coastline coincident with a period of low tide, water flooding into the intertidal area in response to the wind activity will increase the elevation of low tide.

If a high-pressure system develops along the coastline during a high tide, then the water level will be reduced, as the wind stress driving the water offshore is counterbalanced by the tidal influx.

Consequently, the high tide level is reduced, and coastal flooding is minimal in comparison to what would result from a set-up condition.

**Tidal Progression**

*Coriolis Force* causes the high and low tides to progress in a counter-clockwise pattern in the Northern Hemisphere, and in a clockwise progression in the Southern Hemisphere.

The semi-diurnal tidal front pivots on a nodal point ("amphidromic point"), and moves progressively counter-clockwise, requiring approximately 12 hours to complete one cycle.

Each ocean basin has its own amphidromic point, as does each sub-basin.

Thus, in the North Atlantic Ocean, there are separate semi-diurnal amphidromic points for the North Atlantic as a whole (northwest of the Canary Islands), and for the North Sea, Hudson Bay, Gulf of St. Lawrence, and other semi-enclosed basins.

Diurnal tides also progress around amphidromic points, but require approximately 24 h to complete one cycle. The diurnal and semi-diurnal tides are thus out-of-phase.

Areas with mixed tidal patterns will thus feel different proportions of diurnal and semi-diurnal effects during each tidal cycle. The amphidromic points for diurnal tides differ from those of semi-diurnal tides in most basins.

At the diurnal amphidromic point, the diurnal tide will not be perceived, as the tidal front pivots on that location. Diurnal amphidromic points will be influenced only by the semi-diurnal tide. (Analogous to an electric mixer with one fast, one very slow beater)

Research the ‘Saxby Gale’ event. What is the potential impact of climate change and rising sea levels on a similar event to the ‘Saxby Gale’ in the future?
Conversely, at semi-diurnal amphidromic points, only the diurnal tide will be observed (Iles-de-la-Madeleine). As the diurnal tidal range is generally substantially less than that associated with semi-diurnal activity, the semi-diurnal amphidromic points are locations where tidal influence is relatively low.

**Pattern in Atlantic Canada and New Brunswick**

In Atlantic Canada, the semi-diurnal tide progresses south-westward, requiring approximately 4 hours to travel from Cape St. Francis to Yarmouth. Once the tide enters a restricted embayment, such as the Bay of Fundy, its progression is slowed as the water begins to interact frictionally with the bay floor and the coastline.

In the funnel-like Bay of Fundy, the effect is to increase the range of the tide (from approximately 6 m at the bay mouth to 8-10 m in the Peticodiac Estuary, 12-14 m in the Minas Basin), while simultaneously slowing its velocity.

The tidal front requires approximately 1 hour under normal conditions to progress from Yarmouth to Moncton, approximately the same time required for the front to progress from Cape Race to Shelburne NS.

Along the Gulf of St. Lawrence coast, the tide progresses from north to south, taking approximately 2 hours to move from Chaleur to Shediac. See Diagram #2

**Tidal Landforms**

In macrotidal areas, such as the Bay of Fundy, the high tidal range produces a characteristic suite of geomorphic features. Broad tidal flats, coated with fine sand and silt, extend seaward for several kilometres.

At low tide, the ports of the Avon River area and Minas Basin (such as Truro) are inaccessible to ships.

Large meandering tidal channels with steep banks cross the flats. The flats provide important resting and feeding areas for seabirds during low tide.

At high tide, the flats are covered, and powerful currents sweep along the shores and in the main channels. The currents tend to be strongest along the southern bank of the flats, due to the effects of Coriolis Force.

Study a map of Atlantic Canada (or New Brunswick) and compare it to Diagram #2.

Look at the tidal landforms illustrated in the PowerPoint presentation; or look at ones from your own community.
Large transverse bars created by these currents are frequently visible at low tide.

The most distinctive feature of the Gulf of St. Lawrence coastline, particularly evident at Kouchibouguac National Park, is the complex of barrier islands developed along the coast, protecting the lagoons and providing excellent beaches for swimming.

Barrier islands develop as sediment is transported parallel to the shore by longshore drift, which moves sediment from north to south. Sand is brought to the beach by incoming swash waves, which are then refracted seaward as backwash. As swash and backwash occur repeatedly, the sand gradually moves parallel to the shoreline. Barrier island development requires gentle offshore bathymetric slopes, a large supply of sand, and gradually rising sea level.

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Erosion by the tidal currents at Cape Hopewell, where the incoming currents are forced to turn to the northwest up the estuary, has resulted in the formation of Hopewell Rocks. These pillars, up to 25 m high, are composed of relatively easily eroded, red conglomerate.

Erosion by frost wedging along a system of interconnected fractures aligned both parallel to and perpendicular to the coast resulted in the gradual detachment of the pillars from the cliff, giving the pillars their characteristic blocky, rectangular cross-sections.

Tidal action then eroded the bases of the pillars, producing the characteristic 'flowerpot' shape with blocky columns supported on slender, hourglass-shaped bases 8-10 m high. Tidal erosion in the area has been ongoing almost since deglaciation, about 15,000 years ago.

Although the bases appear fragile, the rate of erosion of the bases of the pillars is relatively slow (almost undetectable over the past 10-20 years). Incoming tidal currents are largely focused on the opposite (south-eastern) bank of the estuary, due to the effects of Coriolis Force generated by the rotation of the Earth, and outgoing currents tend to flow most strongly in the centre of the channel. 'Decapitated' pillars are very uncommon.
The rock falls present along the bases of the cliffs are largely the products of frost wedging on the slopes above, rather than being due to destruction of flowerpot pillars by erosion at high tide level. Barring human vandalism, the flowerpots of Hopewell Rocks will remain spectacular for many years to come.

**Historical Influence in Coastal Areas**

High tidal ranges in the Bay of Fundy influence harbour operations. Difficulties in coping with tidal ranges were more profound for sailing vessels than for steamships. Tidal conditions limiting harbour access posed difficulties in maintaining shipping schedules. This handicapped Saint John in the 19th century in comparison to Halifax.

Ports on the northern part of the Gulf of St. Lawrence, including Shippagan and Campbellton, were close to Québec, but far from the settled areas and the commercial and financial centre of the province (Saint John valley). These ports were also not ice-free in winter, and were in areas subject to heavy winter snowfalls and spring flooding. They are also mesotidal, so tidal complications were still present, although not as severe as at Saint John or Moncton.

The only potential port on the southern Gulf of St. Lawrence was Shediac, which was free of ice in most years (if one sailed north-eastward around North Cape, PEI), and had diurnal tides with a low range. Shediac harbour, however, was partially obstructed by shifting sand bars, coastal dunes, and a barrier island complex offshore.

When the (British) Royal Navy was asked to study Shediac in the 1850s, they assessed it as a ‘bad anchorage’, unsuitable for Royal Navy ships. This was crucial because Lloyd’s of London and other insurers would not insure vessels chartered for a designed ‘bad anchorage’. Thus, Shediac received virtually no trans-Atlantic business.

**Influence on Fishing**

**Activity (an example)**

Grand Manan has a macrotidal coast, with tidal ranges typically between 7 m and 10 m.

Seasonal shifts in currents mark the eastern shore, and thus influence both the development of spits and bars and the distribution of nearshore finfish species.

During the winter and spring, the eastern shore is influenced by southerly-flowing currents bringing sediment and relatively cold water from the Black’s Harbour area, and bars and spits extend southwards during these seasons.

How have tides influenced your community's history? (Note that all communities in the Saint John River valley have been influenced by the tides in Saint John Harbour).

How do tides influence operations (shipping, fish harvesters) in your community?
As the current diversion from the Gulf Stream passes south of Grand Manan, the major zones of water mixing are located to the south, in the area of Gannet Rock.

During the summer and autumn, the Gulf Stream-derived current is diverted closer to shore, and the interaction occurs east of White Head Island.

Tidal currents contribute to the development of spits along the eastern shore, especially between North Head and Castalia. In this area, the gently sloping bathymetry allows the flood tide to extend shoreward without interference from offshore currents.

Finfish (especially sardines) following the tidal currents are trapped in stationary weirs positioned along the shore, as they return seaward.

The interaction of the physical environment with human economy and culture is especially evident on Grand Manan Island. All facets of human activity are shaped by the physical geography.

**Influence on Tourism**

Tides are used as a major component in New Brunswick tourist promotion.

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<th>How many tourists visit New Brunswick each year?</th>
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<tbody>
<tr>
<td>Summarize key points</td>
<td>How are the tides used in New Brunswick tourist promotion?</td>
</tr>
<tr>
<td>Initiate discussion of the importance of tides to the communities and to the province</td>
<td>Discussion of any of the above points; or of the points listed in the Conclusions.</td>
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Lesson Extension:
Any of the concepts presented here can be discussed in further detail, emphasizing local circumstances or going into greater depth.

Tidal activity elsewhere in the world could be analyzed in a similar or ‘compare-and-contrast’ fashion. This could include student posters, displays or essays. Suitable locations for contrast include other macrotidal areas (Bristol Channel {UK}, Inchon {South Korea}, Cumberland Sound {NU}, Ungava Bay {QC}); or microtidal areas in Canada.

Connections can be made to historical studies.

Potential for tidal power generation could be discussed – pilot plant at Annapolis Royal (NS), potential in Passamaquoddy Bay, experiments in Bristol Channel (UK) and in South Korea. How would tidal power plants influence fishing and tourism activity in Charlotte County?

Assessment of Student Learning:
Examinations, presentation of posters, displays or essays can be done in response to discussion points raised above.
Semi-diurnal tides in Atlantic Canada

- Hourly position of high tidal front
- Areas affected by diurnal tides

Tides progress counter-clockwise in the Northern Hemisphere
Neap Tide – first or third quarter moon

Spring Tide – full or new moon