Tidal character in local waters.

The source of most of this material is Mofjeld and Larsen (1984), *Tides and tidal currents in the inland waters of western Washington*, NOAA Tech. Memorandum ERL PMEL-56. Another good source of information is Rick Thomson's book *Oceanography of the British Columbia Coast.*

Tidal elevations

The total tidal range is from 1.9 m (Victoria) to 4.4 m (Olympia). The tide is mixed *semidiurnal/diurnal* and has a strong ***fortnightly*** (two week) cycle of spring and neap tides. The dominant tidal constituent in most places is the M_2 tide. The second largest component is K_1 – the diurnal tide due to the *combined effects of lunar and solar declination.* An exception to this pattern occurs near Victoria, where K_1 energy is greater than M_2 energy.

M_2 tides. Maps of amplitude (see figure) of the M_2 tide show a minimum in amplitude off Victoria the primary reflecting boundary at the northern end of the Strait of Georgia. The amplitude of the M_2 tide increases towards both reflecting ends of the basin – northern Strait of Georgia and southern Puget Sound. In the Strait of Juan de Fuca, we find the highest amplitude on the Washington side of the strait, an effect of rotation.

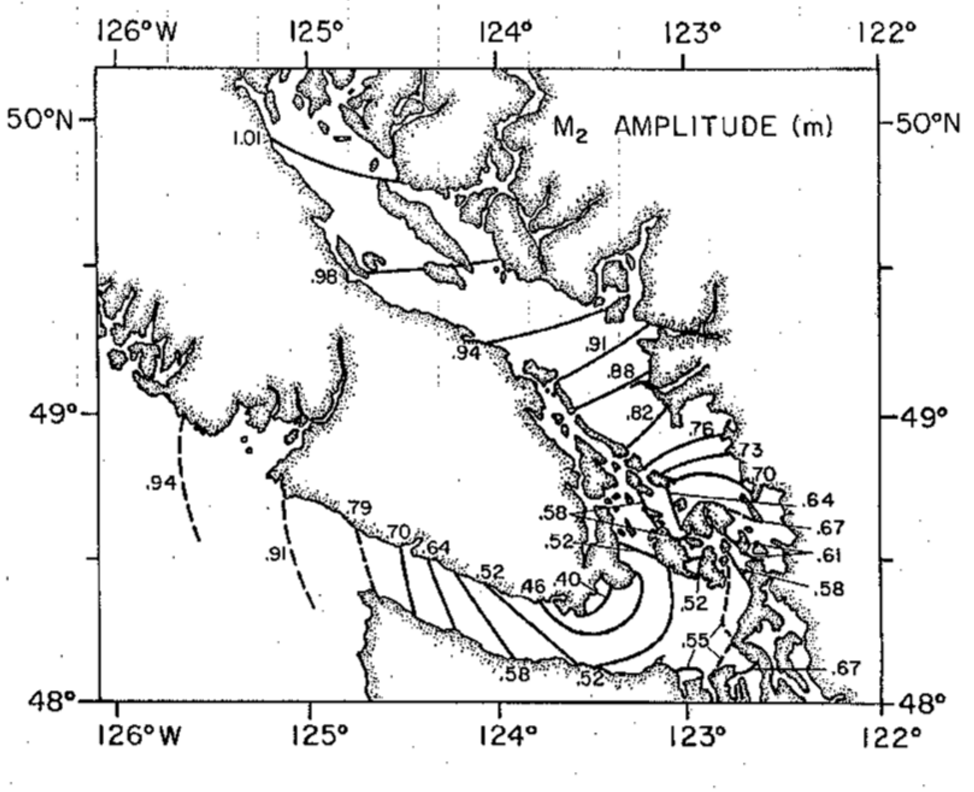


Figure 4. Empirical co-amplitude lines of the M_2 tide in the Straits of Juan de Fuca-Georgia based on a dense net of coastal stations. Dashed lines indicate uncertainty in position. The numbers are amplitudes in meters. Modified from Parker (1977a).

Imagine the incoming Kelvin wave amplifying tidal the range toward the Washington coast (on its right) and an outgoing Kelvin wave with amplitude reduced by friction. This is also the reason the node is located on the Canadian side, rather than crossing the channel.

In the maps of *phase* (not shown), there is a total phase change over Strait of Georgia is about 4 °, which means that the entire basin sees high tide within about 10 minutes – the signature of a standing wave. Near Victoria, however, phase changes a total of about 50° (2 hours) over a relatively short distance. Phase is also observed to change relatively little, ~20° (40 minutes) within Puget Sound (see figure). An exception is the phase on either side of Deception Pass where there is a 40° difference. In amplitude, there is a one-half meter difference on either side of the passage. The tide on the west side is controlled by the tide coming in from the Pacific through Admiralty Inlet. The tide on the east side is controlled by tidal propagation around Whidbey Island. This strong difference in amplitude and phase on either side of the passage (i.e., large lateral sea surface height differences, pressure gradients and water parcel accelerations) is responsible for the treacherous tidal currents found there.

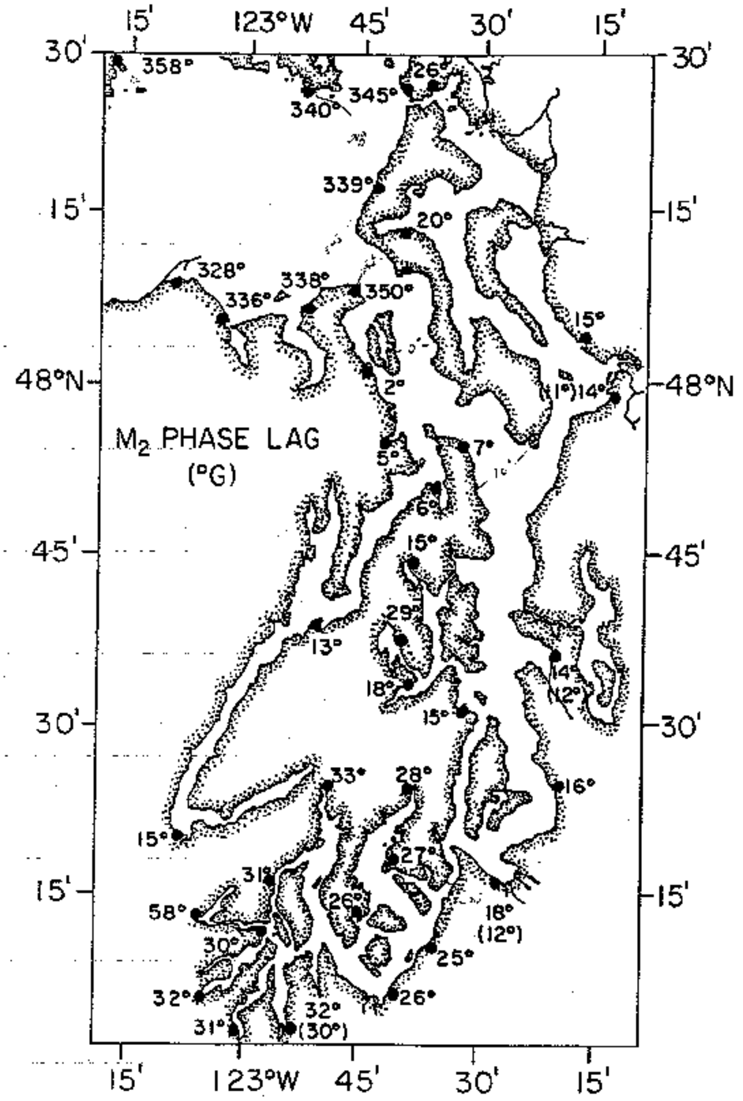


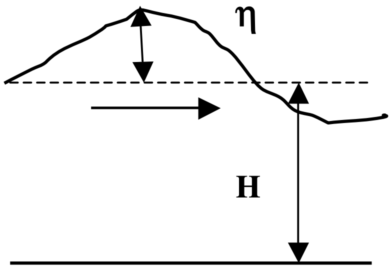
Figure 7. Distribution in Puget Sound of M_2 phase lag in degrees relative to Greenwich transit. From harmonic analyses by the United States. Coast and Geodetic Survey and the National Survey (obtained from various sources).

Overall, the dominant M_2 tide has much of the character of a *progressive wave* in the Strait of Juan de Fuca, which excites *resonant standing waves* in the Strait of Georgia and Puget Sound. There are *partial reflections* at various places, strong frictional damping at various places like the San Juan Islands, and ***co-oscillation*** (i.e, the standing waves interact to produce a unified, coupled mode for all three basins.), that contribute to the complex tidal field that is observed.

K_1 tides. For the K_1 tide, *one-quarter wavelength is longer than the distance from Victoria to the northern Strait of Georgia*, and no node is observed. The amplitude increases towards the far reaches of the strait, and phase progresses continuously. These are characteristics of a partial standing wave modified by friction.

Tidal currents

Tidal currents are predictable from the tidal elevations.



Propagating wave. If the tidal wave is a *progressive wave*, its amplitude is given by

$$\eta = a\cos(kx - \omega t)$$

Then, the ***tidal velocity*** (i.e. how fast particles move in the fluid) can be derived from the tidal elevation using continuity, as

$$\frac{\partial u}{\partial x} = -\frac{\partial w}{\partial z} = -\frac{1}{H}\frac{\partial \eta}{\partial t} = \frac{-a\omega}{H}\sin(kx - \omega t)$$

$$u = \frac{-a\omega}{H}\int \sin(kx - \omega t)\,dx, \quad where\ C = \frac{\omega}{k}$$

$$u = a\frac{C}{H}\cos(kx - \omega t) = a\frac{\sqrt{gH}}{H}\cos(kx - \omega t)$$

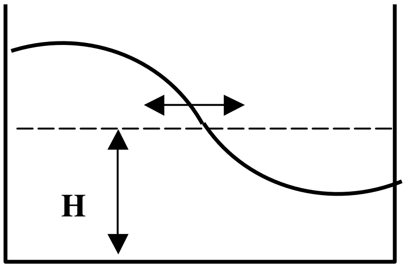
$$= a\sqrt{\frac{g}{H}}\cos(kx - \omega t)$$

For example, for a 1 m amplitude tide in water depth of 100m, the tidal velocity would be 0.3 m/s. The tidal height and tidal currents would be *in phase* with each other, with the maximum velocity coinciding with the maximum in sea level.

Seiche. We can derive the tidal currents for a standing wave, using the same method. The sea level would be

$$\eta = 2a\cos kx \cos \omega t$$

where we recall that the factor of 2 comes from the constructive interference of an incoming and a reflected wave, each having amplitude a. Then velocity is derived as



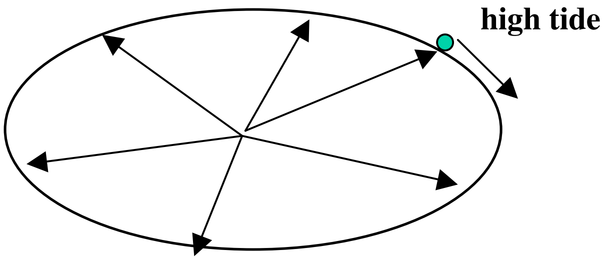
$$\frac{\partial u}{\partial x} = -\frac{\partial w}{\partial z} = -\frac{1}{H}\frac{\partial \eta}{\partial t} = \frac{2a\omega}{H}\cos kx \sin \omega t$$

$$u = \frac{2a\omega}{H}\int \cos kx \sin \omega t \, dx$$

$$= 2a\sqrt{\frac{g}{H}}\sin kx \sin \omega t$$

Thus, the amplitude of the velocity would be double the estimate above (although the same in relationship to the tidal elevation), but the currents would be 90 degrees out of phase with the sea surface height (that is, *the velocity is maximum at the nodes in sea level*).

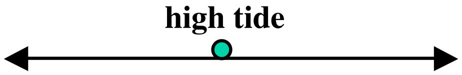
Tidal ellipses. A common diagnostic tool for tidal currents is a plot of tidal current vectors, with the tails at a single point, as a function of time. Over a tidal cycle, the current vectors typically trace out a ***tidal ellipse***. The dot indicates the direction of the current when high tide occurs. The arrow outside of the ellipse is the direction of rotation of the tidal currents. (The direction is not always anticyclonic, which indicates *wave interference* rather than rotation is at work.)



For an idealized Kelvin wave or a standing wave, currents would not be ellipses, but would move and forth along the axis of the inlet. In that case, the tidal ellipse would be a straight line. The dot on the line indicates when high tide occurs.

For a *progressive wave* we would have

For a *standing wave* we would have



In general, tidal currents can have components that are not just along the boundaries. A cross-bay current can result from:

(1) *rotation effects* – water parcels move in anticyclonic (CW in northern hemisphere) ellipses picking up some of the character of an inertial oscillation. In the broadest tidal ellipses, total speed is approximately constant, but the direction changes.

(2) *geometry* -- reflecting waves from several directions can interfere in complex ways.

(3) *lateral eddy motions* generated by sharp features of the coastline

In local waters, tidal currents are generally strong, exceeding 1 m/s in many channels. Tidal ellipses are relatively narrow and aligned along the channel axes, indicating that rotation is relatively unimportant. Broader tidal ellipses occur at the intersection of channels, due to transverse reflection effects (see figure).

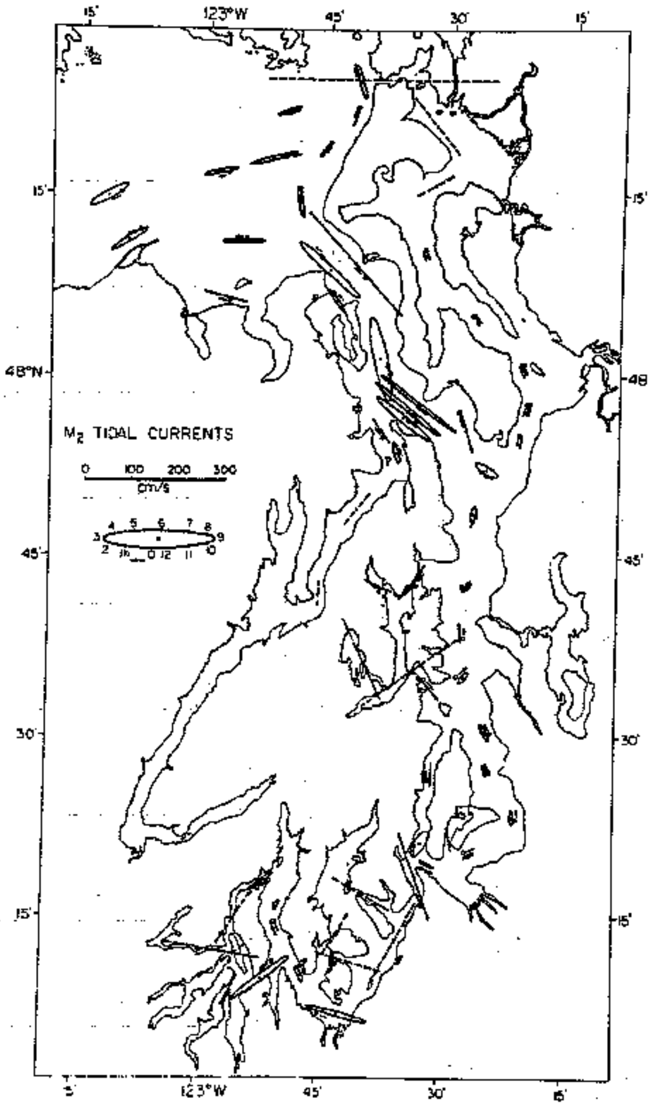


Figure 13. Near-surface M_2 tidal current ellipses observed in Puget Sound. Descriptions of symbols same as Fig. 12. The ellipses were obtained from several sources: 29-day analyses (Table 4) of observations by Cannon et al. (1979), ellipses supplied by Parker (private communication) obtained from a recent observation program by the National Ocean Survey, ellipses from Parker (1977a) and estimates (dashed lines) from the National Ocean Survey Tide Table (1977).