Undertow - Zonation of Flow in Broken Wave Bores

In the wave breaking process, the landward transfer of water, associated with bore and surface roller decay within the inner surf zone, results in a complex vertical profile of water motion that can be divided into 3 zones:

1. Upper Zone: above the wave trough, where mass transport is landward.
2. Middle Zone: below the wave trough and above the boundary layer, where the mean flow is offshore.
3. Boundary Layer: adjacent to the bed, where waves, currents, and sediment interact, and mean flows are generally onshore.
**Undertow - Force Balance in the Surf Zone**

Wave set-up produces a water surface slope (pressure gradient) that acts to counter the landward momentum flux associated with waves (radiation stress gradient).

The turbulence associated with the undertow currents assist in the balancing of forces.

Lab Observations of Undertow (Wave Tank): Comparison to Theory

Dispersal of dyes in wave tanks has demonstrated offshore flow beneath waves (undertow).

Difficulties in measurements, however, have led to advances in the modeling of these water motions.
Field Observations of Undertow – How to Measure Currents?

Numerous researchers conducting field studies have documented the existence of offshore flows at mid-depth.

Data from advances in instrumentation have revealed an alongshore uniformity of undertow, which results in relatively low velocities (0.05 – 0.5 m/s), that do not extend beyond the breaker line.

Electromagnetic Flow Meters - Electromagnetic current meters make use of Faraday’s Law of electromagnetic induction: Movement of a conductor (water) through a magnetic field generates an electromagnetic force proportional to the relative motion of the fluid and the strength of the magnetic field.

Velocimetry – Particle Image, Acoustic Doppler, or Laser Doppler

Wasaga Beach, Georgian Bay (Lake Huron)

Wind, wave, current, and water level measurements were made during a storm.

![Map of Wasaga Beach, Georgian Bay (Lake Huron)](image)

![Graph showing depth vs. distance with markers for wave staff, 512 current meter, 555 current meter, and transmissimeter](image)
Wind and Wave Measurements at Wasaga Beach

Circulation Measurements at Wasaga Beach

Was circulation dominated by undertow or rip currents?
Set Up Measurements at Wasaga Beach

What was the Set-up slope was during the storm?

When did the max set-up slope occur?

Rip Cells
**Rip Cells and Perpendicular Wave Approach**

Horizontal circulation patterns arising from roughly perpendicular wave approach, that include alongshore-directed currents on the beach (feeder currents) and offshore-directed rip currents that cross the breakers in a narrow zone, then spread out and dissipate.

Rip current velocities (0.3 – 1 m/s) are typically much higher than those of undertow, due largely to the concentrated flow patterns.

Giant beach cusps may develop in association with the spacing of rip current channels.

Horns grow at the rip cell divides and embayments grow opposite the locations of the currents.

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**Rip Cell Generation - Longshore Variations in Wave Set-up**

\[
\frac{\partial S_{yy}}{\partial y} = \frac{1}{4} \rho g H \left[ \frac{kh}{\sinh(2kh)} \right] \frac{\partial H}{\partial y}
\]

*Figure 8-3* Schematic illustration of the generation of the cell circulation by a longshore variation in the heights of breaking waves, which produces a parallel variation in the elevation of the set-up within the surf zone. The longshore currents flow from positions of high waves and set-up, to positions of low waves and set-up where the converging currents turn seaward as rip currents.
Rip Cell Generation – Example: La Jolla, CA

Figure 8-6  Rip currents and longshore currents at La Jolla, California, produced by a longshore variation in wave breaker heights caused by wave refraction over offshore submarine canyons. The numbers along the shore are measured values of breaker heights in meters. [Adapted from Nearshore Circulation, F. P. Shepard and D. L. Inman, Proceedings of the 1st Coastal Engineering Conference, 1950. Reproduced with permission from the American Society of Civil Engineers.]

Rip Cells and Oblique Wave Approach

Net alongshore currents develop when wave approach is at an angle to the local shoreline orientation.

Under these conditions, rip channel orientations are skewed, and feeder currents in the direction opposite wave approach are reduced while feeder currents in the direction of wave approach are enhanced.
**Rip Circulation and Nearshore Topography**

Where inner bars are present, feeder currents tend to occupy the trough landward of the innermost bar and are enhanced due to channelization.

These troughs have different effects in response to different wave approach directions:

1. Where orthogonal waves are present, symmetrical rip cells can develop.
2. Where the waves approach obliquely, a meandering longshore current can develop in the trough and intermittently break through the bar to drain seaward.

**Bar Visibility in Argus Imagery**

When submerged, bars can be identified in time-averaged video imagery.

Due to depth-induced breaking, bars are visible as persistent regions of light-color (from turbulence and breaking foam) in time-averaged exposures.
**Temporal Patterns of Rip Current Speeds**

Rip current speeds, averaged over 10’s of minutes, are much lower than those of typical mid-gradient river channels. (~=0.2-0.65 m/s). However, maximum instantaneous velocities have been measured > 2 m/s).

Rip current speeds tend to pulsate at infragravity frequencies, and since sediment transport is non-linearly related to velocity, the pulsing may move more sediment than steady flows.

![Graph showing rip current speeds](image)

**Rip Velocity and Tide**

Rip currents speeds tend to increase during low tide, when a greater fraction of waves break.

A relationship for rip current velocity has been proposed to be dependent on:

1. inputs of nearshore water from waves \(Q_{drift}\) and \(Q_{roller}\),
2. rip channel spacing \(\lambda\), and
3. rip channel cross-sectional area \(R_a\).

\[
V_{rip} = \frac{(Q_{drift} + Q_{roller})\lambda}{R_a}
\]

As the tide drops, water input increases (more breaking waves) and cross-sectional area of the rip channel decreases. Hence, we would expect strong fluctuations in rip velocity through time.

But... do the increased velocities at low tide scour the rip channel and increase \(R_a\)? A possible negative feedback?
**Rip Spacing and Edge Waves**

Bowen and Inman (1969; 1971) proposed that the interaction of standing edge waves with longshore variation in incident waves, produces a strong alongshore variability.

Rip current spacing (and associated rhythmic beach topography) should develop in response to this interaction.

Rip channels tend to maintain their position for periods of weeks or months, and over several storm events.

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**Summary Question Remains:**

*Why are some beaches dominated by undertow circulation (Wasaga Beach, Georgian Bay, Lake Huron for example), whereas others are dominated by well-developed rip cells (California beaches, Australian beaches)?*