# Rip Current Observations and Predictions On Swell Dominated Beaches

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## Abstract

Rip currents are strong seaward jet-like flow off the shore. A field study was conducted to provide rip current observations on swell-dominated beaches. More than 450 days of visual rip current data and associated coastal ocean data were obtained. Analysis indicates that during summer, rip currents are most often produced by swells from the southwesterly quadrant. During the winter, northwesterly swells produce high surf conditions and strong rip currents. In spring, strong seas due to extra-tropical storms cause beach erosion. The beach forms a rip channel between the bars, and moderate waves during low tides can drive strong rips which are dangerous to beach goers. Using the data we tested a diagnostic tool for rip current threat. The tool takes into account tide effects and appears to be capable of giving explicit rip warning, which may serve to reduce drowning deaths.

Key words: Rip current, breaking wave, tide, beach slope, sand.

## 1. Introduction

The United States Lifesaving Association (USLA) has reported that rip currents are the primary source of distress in over 80% of swimmer rescues at surf beaches. In the National Weather Digest, a forecaster, Lascody (1998) reported that, "Rip currents result in more deaths in Florida than hurricanes, tropical storms, tornados, thunderstorms and lightening combined." More than 200 people were rescued by lifeguards as reported by the Daytona Beach News-Journal on July 24, 2007.

Rip current was first named by Shepard (1936) in a note. It is a dangerous killer for swimmers, since it flows out to sea with a speed considerably faster than a strong man can swim. From 1945-1950, Bascom and Isaacs of the University of California performed the "Waves" project using an amphibious truck riding on the beach of Carmel, CA. They found rip currents when above averaged waves break in quick succession and raise the water level inside a bar and the water rushes back in a narrow place. Shepard and Inman (1950) outlined field observations of a near shore circulation system. In the field, Sonu (1972) measured current circulation under high- and low tide conditions and meandering currents on a skewed rip channel. Mei and Liu (1977) theoretically studied the effects of topography on the circulation, and various computer models were developed to simulate field observed rips. There is more than one mechanism to cause rip currents as reviewed by Dalrymple (1978). Field studies (Short, 1985) were attempted to describe the formation of rips. Based on numerous field observations, we illustrate the characteristics of rip currents.

## 2. Characteristics of Rip Currents

Rip currents generated by coastal breaking waves typically contain three components: feeders, a neck and a head (see Figure 1).A rip may seem especially rough or choppy, may have dark color of deeper water, and may or may not have foam. Rip currents are found in calm sea surface in a narrow lane accompanied by enhanced breakers on both sides or at positions of low breaker heights over a rip channel. Most rips move seaward across the breaker zone and spread out to the ocean. Near a structure like a jetty or offshore breakwater, rip circulation can be seen under waves. Sonu (1972) and Aagaard (1997) noted that rip currents intensify at low tide levels. Johnson and Pattiaratchi (2004) measured in-situ transient rip currents by wave groups on a planar beach. On long and straight beaches, a number of rip cells have been observed with even spacing for weeks. More resources of rip currents can be seen at http://www.ripcurrents.noaa.gov which depicts various types of rip currents in the field.

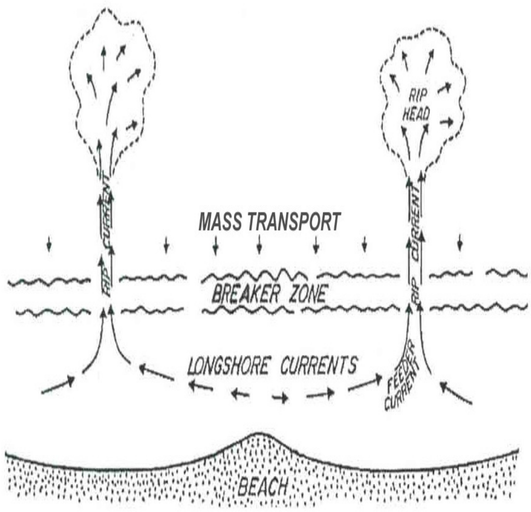

Figure 1: Definition of rip currents

### 2.1 Types of Rip Currents

Rip currents may be classified by the generation mechanisms. The USLA manual edited by Brewster (1995) defines four types of rip currents based on observations of beaches at Southern California beaches:

Fixed Rip Currents – these are found only on sandy beaches in a sand bar system. A fixed rip may lie in a given spot for hours, days or months.

Permanent Rip Currents – these are stationary year round at a specific coastline with headland or a pier (see Figure 2). It is a "drowning" site.


Figure 2: Rip currents due to upwind wave toward a pier

Flash Rip Currents – these transient rips stay about 10-20 minutes and can be dangerous for any swimmers. It is often observed under high energy waves.

Traveling Rip Currents – these rips migrate along the beach and usually occur by a strong oblique swells. It pulls out a large number of swimmers offshore.

## 3. Rip Current Program

On April 6-7, 2004, a technical workshop on rip current was held in Jacksonville, Florida. An overview recommendation was that, "Continued use of forecast indices, customized for local shorelines, appear to be the only viable forecast method at this time." In 2005, a pilot program was initiated by the Meteorological Development Laboratory of the National Weather Service. The program is aimed to develop a diagnostic tool with data collected by lifeguards to improve the forecast by the Weather Forecast Offices (WFO).

### 3.1 Observations on Southern California Beaches

Rip currents are frequently observed on S. California beaches. The proposed pilot program is in collaboration with the local WFO in San Diego, California and with city lifeguards to form a partnership. This partnership was formed to share the surf zone data and to validate forecasts of rip currents.

The first site is the Moonlight Beach, which has a gently sloping bottom of 1/50 with fine to median grained sand of size 0.2 mm to 0.5 mm. The waves are constantly from the southwest and northwest with wind wave period 8-10 sec or swell periods of 10-15 sec. The surf heights and rips are reported twice daily and are saved on a web form interface. The Coastal Data of Information Program of the University of California at San Diego provides the near real-time hourly wave data at 10 meter water depth, which is used as a check up with lifeguard observed surfs. The tide elevation was tracked by the WFO after the rips were reported.

In winter 2009, we expand to San Clemente Beach and Mission Beach to cover the entire coastal marine zone within the San Diego Weather Forecast Office.

Rip current patterns are identified in seasons under various meteorological conditions (Table 1). Rips tend to favor near shore-normal incoming waves with stronger intensity in higher surfs and shorter pulling distance by lower waves. Surf zone width is the on-shore distance between the initial breaking waves and coastline. The surf zone width is a good indicator of rip strength. Typical strong rips are created with a surf zone width beyond 100 yards or wider.

Table 1: Mean wave characteristics observed on Moonlight Beach, California

| **Mean Waves** / Season | Surf Height (ft) | Wave peak period (sec) | Surf Zone Width (ft) |
|---|---|---|---|
| Winter | **3.50** | **13.3** | **330** |
| Spring | **2.89** | **9.8** | **270** |
| Summer | **2.61** | **12.6** | **242** |
| Fall | **2.70** | **11.6** | **250** |

### 3.2 Diagnostic Approach

There are three factors controlling the rips: *wave, mean water levels, and beach slope*. Using a finite element numerical model (Wu and Liu, 1985), the authors compared the model with field data (Wu, et al. 1985) at Torrey Pines Beach, CA and noted that the rip current strength is affected by the sea bottom bathymetry. Generally, a numerical model requires detailed sea bottom bathymetry to produce the current distribution in the field. A model can give more information, but it requires extra data beyond the operational constraints. For the pilot program, three methods of diagnostic tools are reviewed:

1. A check-up template (Engle, et al. 2002).
2. Beach state and wave parameter (Short, 1985).
3. Surf parameter by Guza and Inman (1975).

The goal of using a tool is to estimate the likelihood and rip threat level. The choice of a tool depends upon the availability of data and the adequacy of the model.

**Method 1**: Using the coastal wave data at Daytona Beach, Florida, a check up table is set up to determine the score of rip current threat level. This approach is applied in the east coast based on local wind waves, which is not inclusive for swells on west coasts.

**Method 2**: Define rip occurring state by a parameter, $\mathbf{\Omega}$. The idea is to incorporate the wave characteristics and sediment motion as adopted by Dean (1973). The $\mathbf{\Omega}$ is defined as $H_b / (w\, T)$, where H is the on-shore breaking wave height in meters and T is the peak period of the corresponding wave in seconds, and *w*, the suspended sand particle fall velocity in meter per second. The subscript $_b$ denotes wave breaking condition.

Short (1985) noted that rips occur most frequently in a range when $1 < \Omega < 6$. This guideline has been applied to beaches in Australia which is also dominated by swells. The lower bound value may change with the beach status, when applying the method.

**Method 3**: Guza and Inman (1975) defined a criterion for standing edge wave condition as: $\varepsilon = a_b\, \omega^2 / g\, tan^2\beta$, where the angular frequency $\omega = 2\,\pi\,/\,T$, and $a_b$ is the amplitude of the breaker. The g is gravitational acceleration and tangent $\beta$ is the surf zone gradient.

By analogy with breaking wave criteria, it is suggested that $\varepsilon > 20$ is for high dissipative spilling breakers on flat shore. $\varepsilon < 2.5$ is for high reflective beach where no rips are seen; For $2.5 < \varepsilon < 20$, the rips are active for waves on an intermediate beach with bars and holes.

In Southern California, winter high surf pulls sand from the berm and deposits it into the bars. In summer time, low swell rebuilds the berm and keeps it. The beach foreshore slope varies during swell and storm periods, we have to specify for it respectively.

### 4. Field Data and Model Applications

We have evaluated one year data sets with respect to wave observations and rip currents. Table 1 displays the ranges of surf heights which rips took place. The visual observations are viable but the mean difference between modeled and observed wave heights are within the limit of variation. Table 1 indicates that waves are dominated by swell waves of 9-12 sec.

Rip current strength can be weak, moderate and strong, depending upon the seaward distance pulled by the rips with respect to the surf zone width. Strong rips pull the water beyond twice of the surf zone width and weak rips appear within the surf zone. Table 2 shows that surf heights less than 0.5 m generates no or weak rips, and weak or moderate rips are mainly created by surf values of 0.5 – 1.0 m and strong rips are largely generated by surf values higher than 1.0 m. This outcome was from observations on San Clemente Beach.

It should be noted that surf height alone is not the sole parameter to determine the rip currents. During summer period, due to existing holes eroded in the spring, even low waves can cause strong rips at low tide levels. The surf zone width is wider at low tide level and thus more breaking waves contribute to wave setup and intensify the flow. In an experiment, Short (1994) demonstrated the tide effects during high and low tide water level in the surf zone (see Table 3). Rips can be dangerous under incident waves of 1 m or less.

Table 2: Rip intensity vs. incident wave height values

| Rip Intensity / Surfs H (m) | Weak | Moderate | Strong | No Rip |
|---|---|---|---|---|
| H < 0.5 | 2 | 0 | 0 | 16 |
| 0.5< H < 1.0 | 9 | 7 | 1 | 10 |
| 1.0< H < 2.0 | 5 | 10 | 6 | 2 |
| 2.0< H <3.0 | 0 | 1 | 5 | 2 |

Table 3: Tide effects on rip currents and surf zone width

| Rip current properties / Tide level | Max rip speed (m/sec) | Distance Traveled (m) | Surf Zone Width (yards) |
|---|---|---|---|
| Low tide (0.5 m) | 0.60 | 405 | 80 |
| High tide (3.0 m) | 0.25 | 204 | 40 |

Using 2007 observed data, we calibrated the methods M2 and M3 with waves and beach conditions, Then we applied methods M2 and M3 for summer period in 2008 (see Figure 3.1 and 3.2). Figure 3.1 shows that M2 hits most days within the range of 1 to 6 with a few rip cases which are slightly below 1.0, while M3 (Epsilon value) gives many lower values below the limiting bound 2.5.

The application of M3 is sensitive to the choice of beach foreshore slope. As beach face is continuously deformed by the incident waves. On the other hand, the mean sand grain size keeps relatively constant in the summer period. Both M2 and M3 assume near-shore normal waves, if incident wave angle is larger than 45 degree, the on-shore wave height must be calculated. In the winter time, beach face is eroded. The foreshore slope is higher and thus the fall velocity of mean sand grain is also increased.

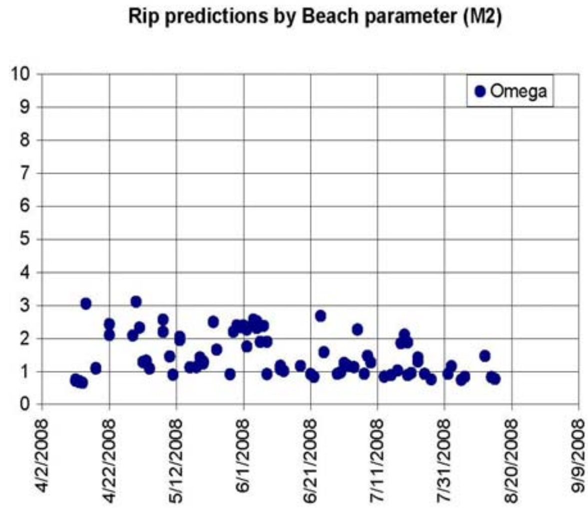


Figure 3.1: Rip predictions by beach-sand M2

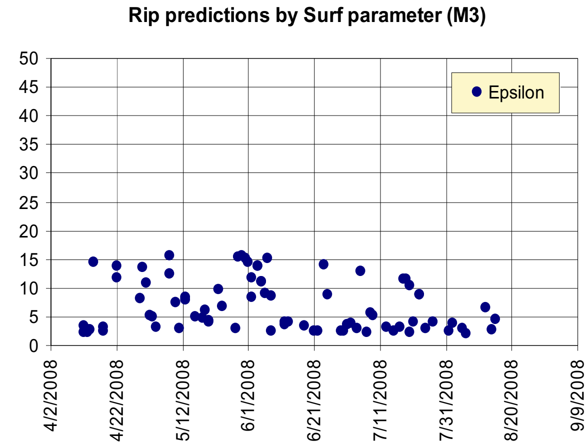


Figure 3.2: Rip predictions by surf parameter M3.

## 4.1 Model Performance

To compare the performance of the two methods, M2 (wave-sand type) and M3 (surf) are tested against daily data in the summer 2008 at Moonlight Beach. The probability of detection is checked with lifeguard observations. False alarm rate is counted and the success ratio is calculated. A critical skill index is listed in Table 4. The M2, which considers wave and sand size, gives a higher success rate than that of beach formula M3 which has lower success ratio. In addition, the value of M3 is inversely proportional to the square of the beach gradient. As mentioned earlier, the beach front is more volatile during the storm waves.

Table 4: Critical skill Index scores for M 2 and M 3

| SCORE / Methods | POD Probability of detection | FAR False Alarm rate | SR Success ratio | CSI Critical success index |
|---|---|---|---|---|
| Wave-Sand M2 | **0.81** | **0.25** | **0.75** | **0.631** |
| Surf - Beach M3 | **0.63** | **0.43** | **0.57** | **0.495** |

More analysis will be conducted in collaboration with other Weather Service's Forecast Offices. We aim to examine the threshold values that may indicate local rip hazards such as the onset of a rip current outbreak.

**5. Conclusion and Remarks**

We collaborated with lifeguards and observed rip currents for more than one year data. It was found that rips are favored near shore-normal incident waves at low tide levels, and rips frequently occur with low steepness swells on mild beach slope. Using the field data, we validated a diagnostic tool based on wave and sand grain property to predict rip current occurrence. The model performance has been checked against with the field data. Good score was gained for surf heights ranged from 0.5 m to 1.0 m. We confirm that accurate surf height plays the key role in the prediction of rip hazards. This tool developed on the Southern California beaches will be tested to other beaches with rip hazards.

Rip currents can occur under various wave and beach conditions. The challenge in rip current forecasting is to identify the period when rip currents are likely to be strong and pose a threat to beachgoers. As waves vary with the tidal cycle near the shore, the dangerous rips are often observed at low or falling tide. While bars and holes are sufficient condition for rip potential; by theory, rips cannot be created without enough water volume flux from onshore waves strike on the shore. A measure of volume flux by the breaking waves can be a means for specifying the strength of rip currents.

With the advancement of computing capability, community models are developed by Haas, et al. (2003) and Chen, et al. (1999). However, numerical modeling results must be verified with field measurements. An Argus imaging technique promoted by Holman, et al. (1993) and X-band radar by Trizna and Hathaway (2007) showing images of marine coastal waves and inshore morphology may be utilized to watch mega rips. These new tools offer more insights of rip causes and provide a roadmap for future operation.

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