14 Rip Current Hazards on Large-Tidal Beaches in the United Kingdom

Timothy M. Scott, Paul Russell, Gerd Masselink, M. J. Austin, S. Wills, and A. Wooler

CONTENTS

INTRODUCTION

Beach hazards have historically been addressed in terms of damage to property and infrastructure. In recent years, scientists have started to develop an understanding of hazards and risks to beach users (Lushine, 1991; Short and Hogan, 1994; Leahy et al., 1996; Lascody, 1998; Short, 1999; Short, 2001; Engle et al., 2002; Hartmann, 2006; Sherker et al., 2008). Application of improved knowledge of beach morphodynamics and rip currents for beach safety was initiated in Australia, principally through the work of Short (1999). He applied beach state models to hazard assessment, leading to the development of inventories of beach types and hazards for all Australian beaches.

The Royal National Lifeboat Institution (RNLI), the principal provider of lifeguard services in the United Kingdom, commissioned research to further understanding of beach morphodynamics and hazards (Scott et al., 2007, 2008, 2009; Scott, 2009). The research outcomes provide a basis for the development of practical hazard assessment tools and improved lifeguard training and public education. These elements are integral parts of the RNLI risk assessment and mitigation program. One of the principal goals is to improve understanding of rip current hazards at medium- to high-energy macro-tidal beaches.

Rip currents have long been documented as significant hazards to waders and swimmers (Shepard, 1949; McKenzie, 1958; Short and Hogan, 1994; Short, 1999; and MacMahan et al. 2006). Lascody (1998) stated that rips in Florida on average caused more deaths than hurricanes, tropical storms, lightning, and tornadoes combined. Recent investigations of beach hazards in the UK, Australia and the United States indicate that rip currents represent the single most significant cause of rescues and fatalities for recreational beach users (Short and Brander, 1999; Scott et al., 2007; Scott et al., 2008). Specifically, Scott et al. (2008) noted that 68% of all incidents recorded by the RNLI on UK beaches were due to rips.

Most previous investigations of rip current hazards concerned micro- and meso-tidal environments (<4 m tidal range). The macro- to mega-tidal beaches (4 to 12 m tidal range) that dominate the UK coast introduce unique complexities into understanding beach hazards. In addition to large tides, the UK beach environment is characterized by a mixed, often high-energy, wave climate, and complex geological history.

The nature of rip currents and their spatial and temporal distribution and relationship with beach type and morphology are of prime concern (Scott, 2009). The aim of this chapter is to synthesize new insights regarding the controls on the temporal hazard signature (THS)—the variation in space and time in the types and severities of bathing hazards.

ENVIRONMENTAL SETTING

The UK by virtue of its location and geologic setting possesses a broad spectrum of beach environments along its 5,000-km shoreline. Its beaches attract large numbers of visitors annually due to their aesthetic, sport, and recreational appeal and they provide pivotal support to the tourism industry in many regions. Characterizing rips and recreational beach hazards in a UK setting requires a comprehensive understanding of physical beach environments.

The wide variety of beach systems throughout England and Wales is driven by the along-coast variability of static and dynamic environmental factors. The three most important factors are geology, sediments, and external forcing (wind, waves, storms, and tides). The spatial variability in boundary conditions is responsible for geographical variations in coastal morphology and morphodynamics (Davies, 1980) that in turn control the levels of physical hazards.

Steers (1960) attributed the diversity in coastal geomorphology in England and Wales mainly to varieties of rocks. The large-scale solid geology, characterized by a decrease in age and rock resistance from west to east, forms the template of the overall coastal topography and creates a contrast between the high-relief, mainly rocky, west coasts of England and Wales, and the low-relief, mainly unconsolidated, east coast of England (Clayton and Shamoon, 1998). Coastal sediments were largely derived from the most recent glaciations that deposited large quantities of heterogeneous materials. The abundance of these coastal sediments significantly affects beach morphology, often constraining the extent of morphological evolution (Jackson et al., 2005) and affecting the hydrodynamic regime.

Beach sediments are transported mainly by tide- and wave-driven currents that exhibit large spatial variabilities (Figure 14.1). Most of the coasts experience macro- (41.7%) or mega-tidal tide ranges (42.2%), and the mean spring range (MSR) is 5.77 m. The largest tides (MSR >12 m) occur in the Bristol Channel due to the funneling effects of the coastal topography. The smallest tides (MSR = 1.2 m) are experienced in the lee of the Isle of Wight.

Some of the most energetic wave conditions are experienced southwest of the UK, where the mean significant wave height (H_s) is between 1.25 and 2.25 m and the wave climate is a mixture of Atlantic swell and locally generated wind waves (Figure 14.1b). The lowest wave conditions prevail in the northwest and east of England, where wind waves are predominant and mean H_s values are less than 1 and 1.25 m, respectively. Exposure of southwest England to the Atlantic Ocean increases the contributions of long-period swell waves to the wave spectrum. The complexities of coastal orientation and exposure around the coasts of England and Wales lead to beach waves that are a dynamic balance of high- and low-energy and wind-swell-wave components that are often characterized by a bi-modal wave energy spectrum with multiple directional sources (Bradbury et al., 2004).

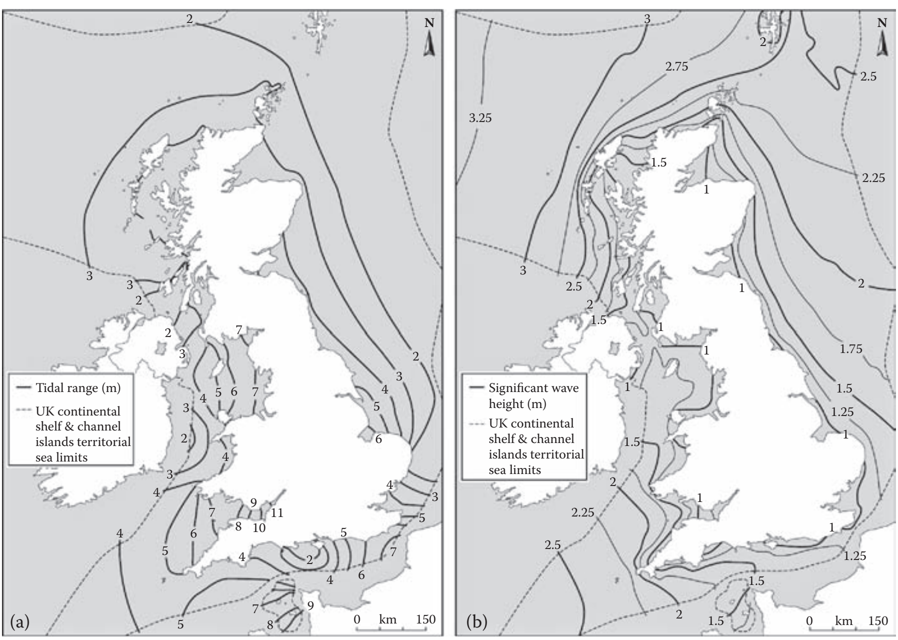

FIGURE 14.1 (a) Mean spring tide range (based on data derived from an average tidal year). (b) Annual mean significant wave height based on hourly model hindcast data over 7 years. (*Source:* Adapted from Department of Business Enterprise and Regulatory Reform, 2008).

FIGURE 14.2 (*See color insert.*) Crooklets Beach, north Cornwall provides an example of the complex nature of physical hazard dynamics. Low-tide rip systems controlled by transverse bar, and rip beach morphology and upper beach morphodynamics modified by geologic control and groundwater seepage, constrain and influence surf zone currents and hazards during mid and high tides. Inset shows location of southwest England study region (grey box) and Crooklets Beach location (solid circle). (Photo courtesy of Tim Scott.)

Mean seasonal variations in wave climates are significant in many coastal regions with strong summer to winter variations. Wave buoy data from the Atlantic southwest coast of England show that significant wave heights range from 2 to 5 m from summer to winter, respectively. Joint wave distributions indicate that a significant portion of the increase in energy is due to winter storms with associated long-period waves (T_m up to 14 sec). Southwest England provides a unique site for investigating the role of rip currents and beach hazards for sediment-limited, high-energy beaches with large tidal ranges. These beach environments present the greatest risks to beach users in England and Wales (Figure 14.2).

TEMPORAL HAZARD SIGNATURE (THS)

Beach hazards, like morphodynamics, vary on a range of time scales. For the successful provision of beach safety services, it is crucial to understand the temporal and spatial variabilities of the prevailing hazards. Figure 14.3 is a conceptual summary of the key findings within the context of a THS for high-risk bathing beaches. The framework provides a structure for beach hazard assessment as defined by beach type, environmental setting, and hydrodynamic forcing.

This approach stems from Short and Hogan (1994), where modal and wave height-modified beach hazard ratings were defined for each beach state described by Wright and Short (1984) and Masselink and Short (1993). This research initiative considers the intermediate beach groups [low tide terrace + rip (LTT+R) and low tide bar and rip (LTBR)] redefined by Scott (2009) as the most hazardous. Dissipative and ultra-dissipative beaches have relatively low hazard ratings because the absence of sand bars means low rip activity.

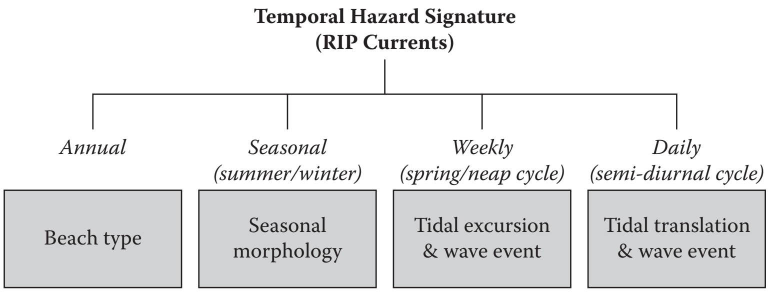

FIGURE 14.3 Time components of the temporal hazard signatures for the macro-tidal beaches studied. Principal environmental controls on rip current hazards associated with each time scale are indicated.

Beach Type

The physical characteristics of 98 beaches in England and Wales were sampled, including morphology, sedimentology and hydrodynamics (Figure 14.4). Cluster analysis of this beach database produced a hazard classification comprised of twelve beach groups—each with a distinct hazard signature (Scott, 2009). This model provides the framework for assessment of the distribution of rip current morphology and characteristics of physical hazards at all 76 RNLI beaches that were actively patrolled from 2005 to 2007 (Figure 14.4).

Few researchers other than Short (1993, 1999 and 2001) and Short and Hogan (1994) included the concepts of morphological state and beach type in hazard evaluation. In many cases, only wave height, period, and direction were used (Lushine, 1991). Ten of the twelve identified beach groups are represented within RNLI lifeguard patrolled locations (Scott, 2009). Figure 14.5 shows the ten groups with idealized morphological forms and numbers of representative RNLI beaches for each group. These contrasting study environments provide a unique opportunity to identify specific hazard characteristics (Scott, 2009).

RNLI incident records showed that rip currents were the causal hazards for 68% of all reported incidents between 2005 and 2007. In particular, the high-energy, intermediate beaches with low-tide bars and rip morphology (LTT+R and LTBR) present the greatest rip current risk to recreational beach users. Eighty percent of all reported incidents on these beaches were due to rip currents (Figure 14.5). These high-risk beaches, representing 59% of the west coast beaches in Devon and Cornwall and 77% of all RNLI patrolled beaches, also attracted the greatest number of visitors (Figure 14.6).

The importance of spatial variations of wave energy levels is related to minimum wave energy thresholds for transport (Masselink and Short, 1993) and for the beach groupings defined herein as the threshold energy levels required for generating infragravity waves (Guza and Thornton, 1985) and rhythmic bar morphology. A critical wave energy threshold is defined as H_s of 0.8 m and T_p of 8 sec to separate

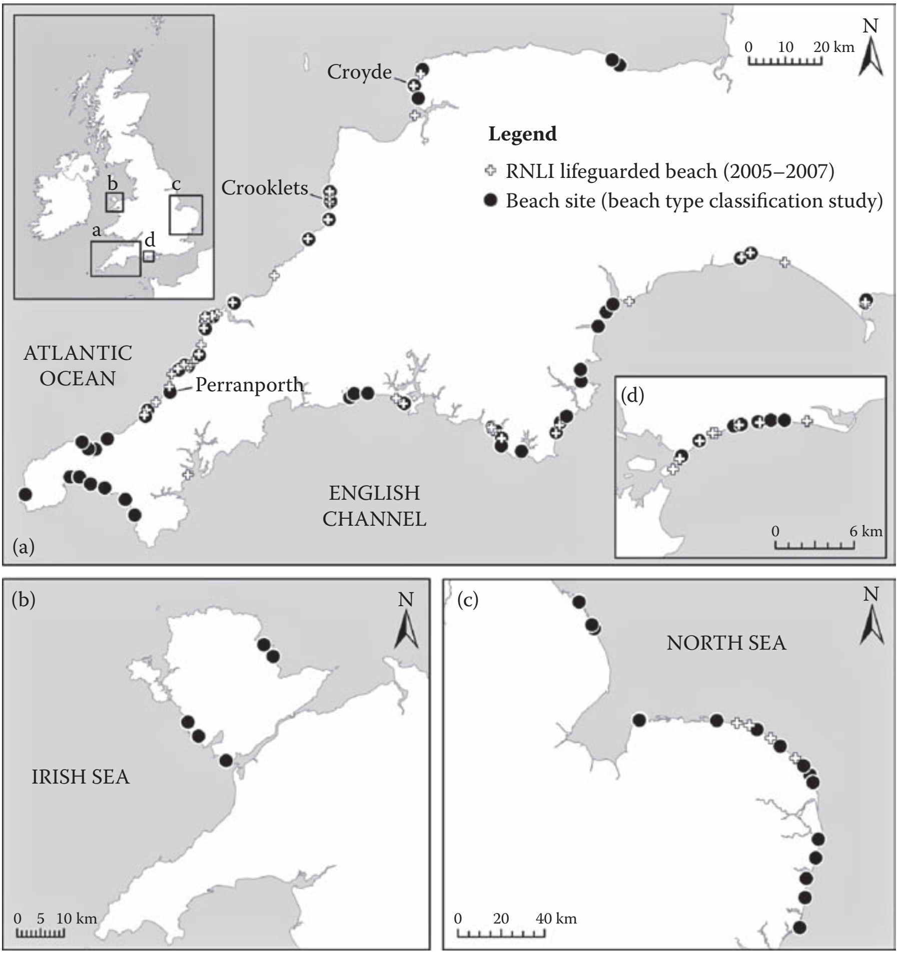

FIGURE 14.4 United Kingdom map indicating locations of all 98 beach sites included in the beach type classification study (black circles) and 76 beaches lifeguarded by the Royal National Lifeboat Institution from 2005 to 2007 (white crosses). Subplots and inset represent enlarged views of region indicated on the overview map.

low- and high-energy intermediate beach groups. This delineation separates beaches dominated by long-period, open-ocean swells from beaches with fetch-limited wind waves. Controlling for the presence or absence of bar and rip morphology, this distinction is key in understanding how hazard levels vary by beach type.

Jackson et al. (2005) and McNinch (2004) suggested that hard-rock geology acts to constrain and modify morphodynamic processes by controlling sediment abundance and depth to geologic substrate. The combination of beach type and environmental controls (geologic and structural constraint, sediment abundance, drainage, and backshore geomorphology) define the potential for rip current activity. Rips can take on a number of forms based on their forcing and controlling mechanisms

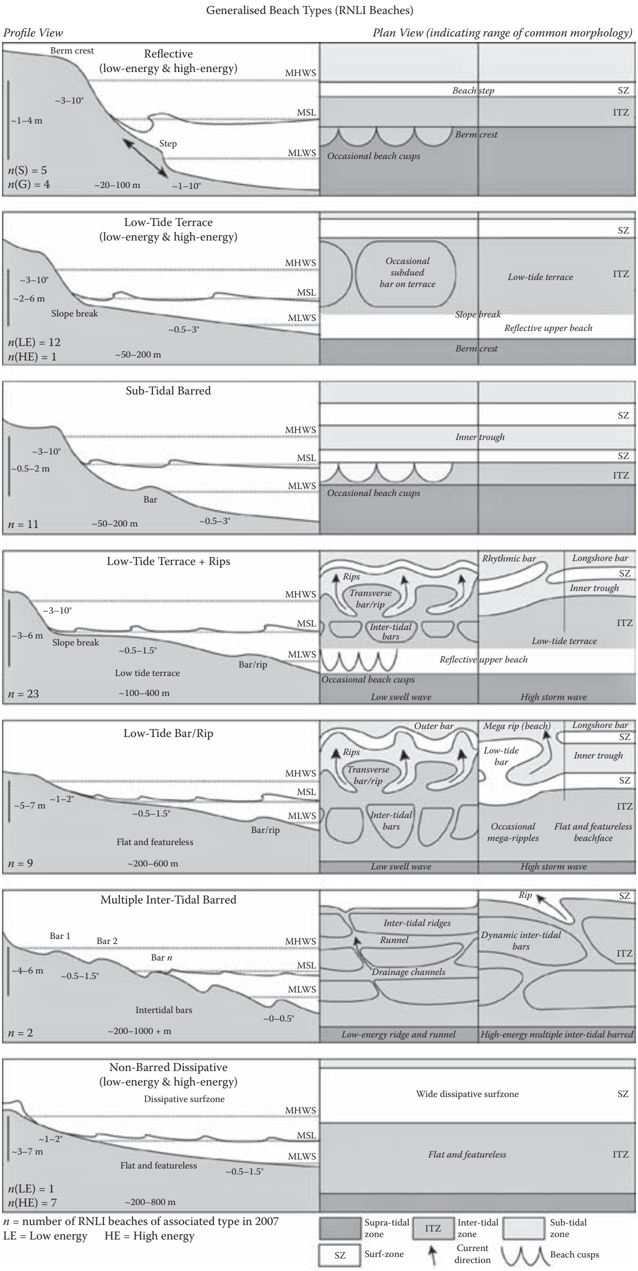

FIGURE 14.5 Generalized beach types (Scott, 2009) associated with Royal National Lifeboat Institution patrolled beaches in 2007. The number of beaches associated with each type (*n*) is indicated as are typical morphological features and commonly observed variabilities (plan view illustrations in right-hand panels).

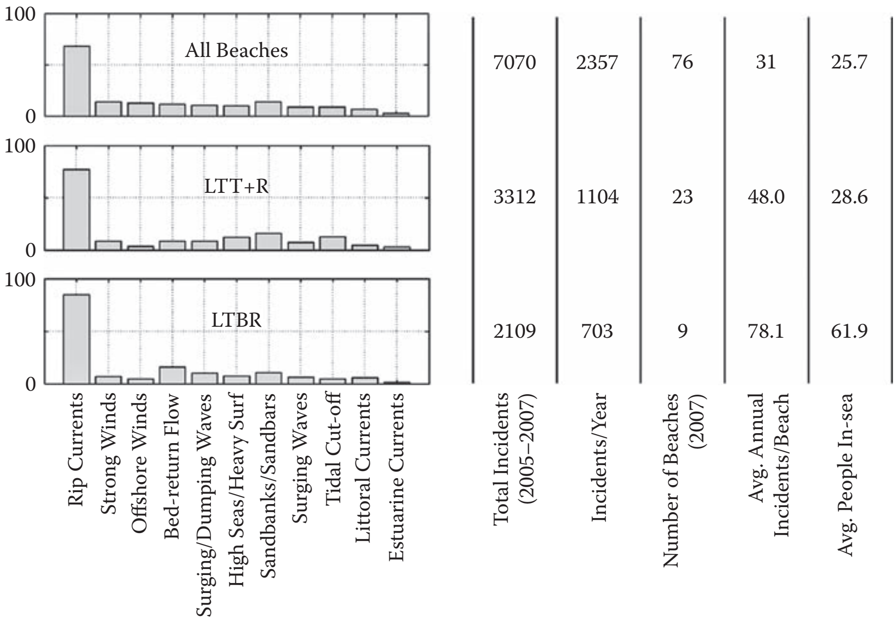

FIGURE 14.6 Distribution of environmental causes of hazards for Royal National Lifeboat Institution incidents at all beaches (top) and only LTT+R and LTBR beaches with rip morphologies (middle and bottom). Data collected from 2005 to 2007. Additional statistics provide incident and beach population numbers.

(Short, 1985). Accretionary beach rips and topographically controlled rips are the largest contributors to beach hazards for LTT+R and LTBR beaches (Scott et al., 2009; Figure 14.7). The temporal and spatial variations of these rips are due to large tidal excursions. Low-tide regions are dominated by beach rips within the sub- and low-tide rhythmic bar systems (Figure 14.7, left). During high-tide, these systems are often in >8 m water depth, and surf zone processes interact with a steeper upper beach (LTT+R examples). In cases with significant geologic control, topographic rips are located up to 500 m landward of the low-tide shoreline (see Figure 14.2 and Figure 14.7, right panel).

Unlike some of the more reflective or ultra-dissipative beach groups where large tidal range or sediment size restricts temporal state change, intermediate dynamic LTT+R and LTBR beaches exist around critical thresholds of the dimensionless fall velocity $\Omega = H_b/w_sT$, where H_b is breaking wave height, w_s is sediment fall velocity (related to sediment size), and T is wave period (Gourlay, 1968; Dean, 1973; Davidson and Turner, 2009). Variation of Ω around these threshold values is controlled by intra-annual wave conditions (wave steepness) and hence seasonal beach erosion and accretion.

Seasonal (Summer and Winter) Morphologies

Seasonal monitoring of hydrodynamics and morphology at LTT+R and LTBR beaches identified key mechanisms controlling the temporal hazard signature (THS).

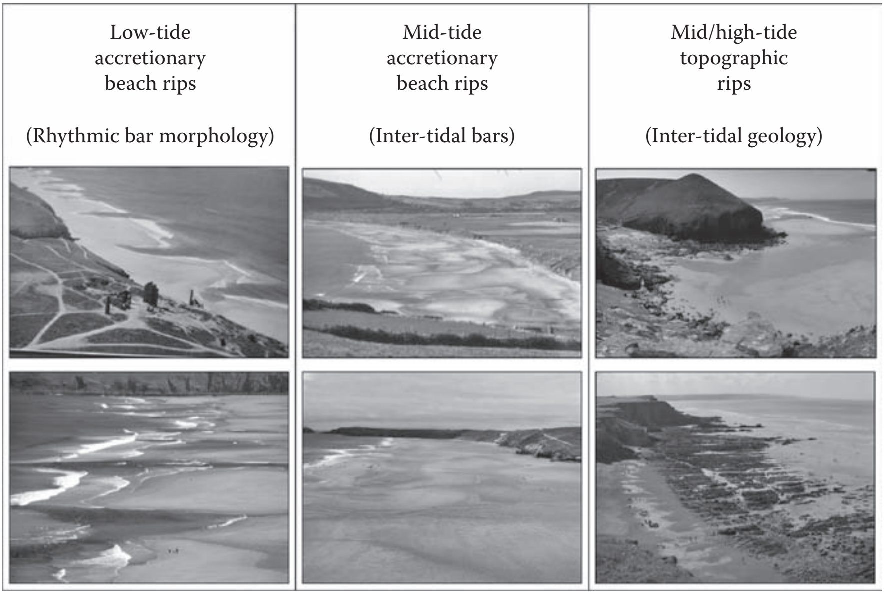

FIGURE 14.7 High-risk rip current types in the United Kingdom identified by this study as responsible for most rip-related incidents and rescues reported by the Royal National Lifeboat Institution.

Topographic surveys and video imagery documented intra-annual and seasonal morphological changes at LTT+R and LTBR beaches (annual H_s = 1.25 to 2.25 m; MSR = 4.2 to 8.6 m). Offshore sediment transport (below MLWS) and intertidal beach lowering occur during high-energy winter periods. These erosive periods create flat, featureless, intertidal zones and quasi-linear longshore bar and trough (LBT) sub-tidal bar systems. Figure 14.8 illustrates the subsequent accretion and re-establishment of rhythmic, and then transverse, lower inter-tidal bar and rip systems measured during the lower energy spring and summer period at Perranporth. The transition of beach morphology to an increasingly three-dimensional state under decreasing wave energy conditions as well established (Wright and Short, 1984).

Figure 14.8a shows time-averaged oblique (unprocessed) video imagery, indicating sub-tidal bar crest locations. Figure 14.8b illustrates the accretionary transitions through monthly collected topographic RTK-GPS survey data in conjunction with the ortho-rectified video images from Figure 14.8a. This sequence clearly shows the extent of bar development in the mid-tide region, the increasing three-dimensional nature of the low- and sub-tidal bar, and rip configurations leading to exposure of the accreting low-tide bar during the September 12, 2007 survey.

The cross-shore distribution (through tidal elevation) of incidents, normalized by frequency of tidal elevation, is shown in Figure 14.8c. During the early season (May to June), incidents are largely restricted to the low-tide region. The increased contributions of mid- and high-tide incidents to cross-shore distribution throughout the rest of the season (July to October) can be linked to the development of inter-tidal bars at Perranporth. The increasing bar morphology within the higher tidal regions

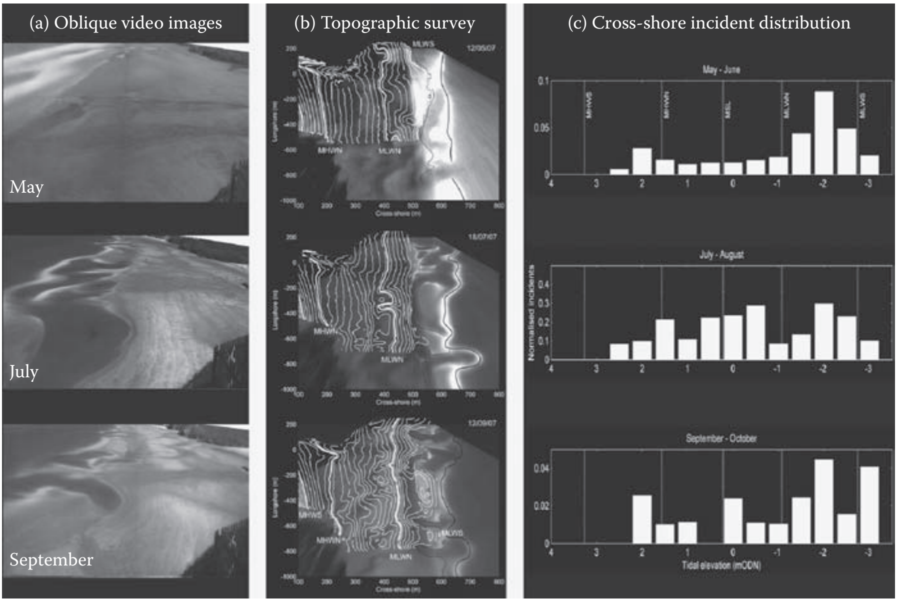

FIGURE 14.8 (a) Oblique time average video imagery and (b) topographic RTK GPS survey data combined with rectified time-averaged video imagery illustrate seasonal variations in bar morphology at Perranporth Beach in 2007. Perranporth represents a typical LTBR type; the mid and low tide bar transitions are similar to those seen at LTT+R beaches. Mean tidal elevations (bold white) are labeled and approximate location of the shoreline (black dashed) and the wave break point bar (black solid) are indicated. (c) Incident occurrence at Perranporth associated with vertical beach elevation provides an insight into the cross-shore locations of incidents. Incident occurrence at 0.5-m intervals is normalized by frequency of tidal elevation for early, mid, and late season. Dashed lines indicate mean tidal levels.

and progressive three-dimensional transition and onshore migration of the low- and sub-tidal bar systems during the summer accretionary waves extends rip activity through more of the tidal cycle and enhances the hazards. Magnification of temporal rip hazards in combination with greater beach populations during warmer summer waters resulted in an incident peak at Perranporth (Figure 14.8c).

Waves

Wave forcing over a dynamic bar morphology drives rips (Sonu, 1972; Haller et al., 2002) and is the principal component of rip prediction (Lushine, 1991; Engle et al., 2002). Thus, if waves drive rip circulation, how do event-scale variations in the wave climate (days to weeks) affect hazards, and do rip hazards increase linearly with wave height?

The joint wave distribution of the entire 2007 patrol season from nearshore wave buoy records (10 m depth) at Perranporth, west Cornwall show that the highest frequency wave heights were from 0.5 to 1 m with peak wave periods of 4 to 12 sec. Joint distribution clusters identify short-period, medium-energy events

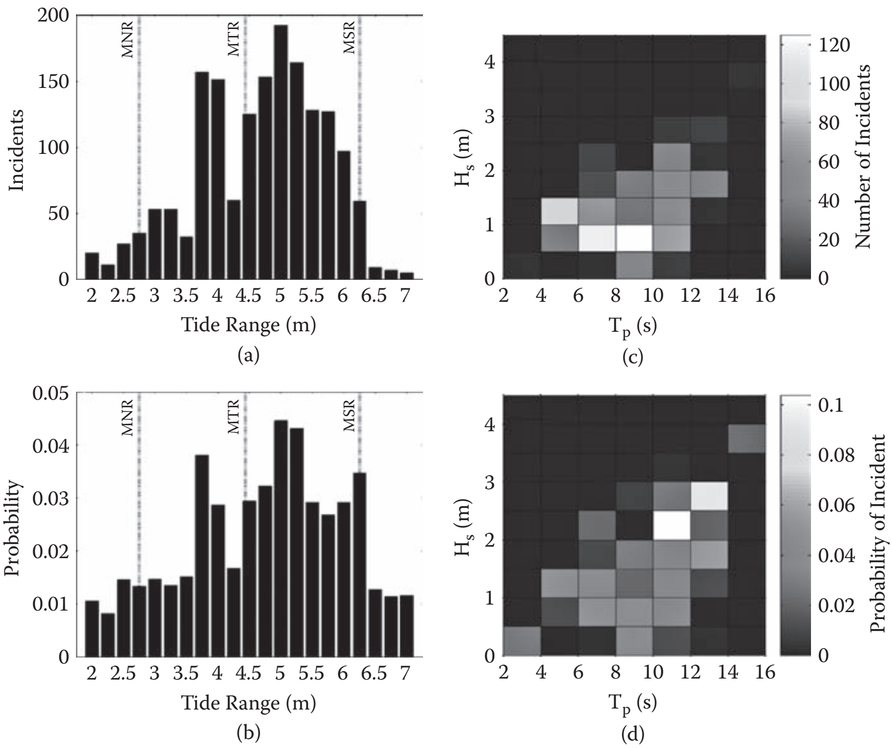

FIGURE 14.9 (*See color insert.*) Histograms of tidal range associated with (a) incident frequency and (b) probability of incident (*IR*). Dashed lines indicate mean spring range (MSR); mean tidal range (MTR) and mean neap range (MNR) are marked. Data represent incidents recorded at all studied west coast LTT+R and LTBR beaches in 2007. Two-dimensional frequency matrices of joint wave distribution are associated with (c) number of incidents and (d) probability of incident. (*Source:* Data recorded during patrol hours, 2007 patrol season.)

and long-period, low-energy events as most common. Incident counts show medium- to long-period, low-energy wave conditions (H_s of 0.5 to 1 m; T_p of 6 to 10 sec) associated with the highest number of rip incidents (241) at the six west Cornwall LTT+R and LTBR beaches (Figure 14.9). This represents 28% of all rip incidents at the selected beaches during the season. Unsurprisingly, the in-sea populations were largest during low-energy conditions (H_s < 1.5 m).

The probability of incident (*IR*) for recreational beach users is expressed as *IR* = *Re*/*P* where *P* is the number of people in the water and *Re* is the number of individuals assisted or rescued. *IR* is highest when associated with high-energy wave conditions (H_s > 2 m) with peak periods >10 sec (Figure 14.9d). This reflects a small number of incidents that occur during the early season when hazardous high-energy conditions combine with low in-sea populations, leading to low levels of hazard exposure. About 75% of beach users were in the sea during low-energy wave conditions (H_s of 0.5 to 1.5 m); longer-period swells accounted for a large proportion (36%) of incidents under low-energy conditions. This highlights the importance of understanding hazard levels associated with lower-energy conditions where beach user exposure to rip hazards are high.

Tides

Rip hazard prediction has begun to incorporate tidal modulation (Engle et al., 2002). Tidal level has been widely observed to modify rips, increasing flow speeds at lower tides (Sonu, 1972; Aagaard et al., 1997; Brander, 1999; Brander and Short, 2001; MacMahan et al., 2005). For macro-tidal beaches, tidal modulation of rip hazards is exerted through two principal mechanisms: tidal excursion and translation.

Tidal Excursion (Spring/Neap Cycle)

The spring/neap tidal cycle creates significant temporal variations in tide ranges at macro-tidal beaches that have wide intertidal zones and large tidal excursions. This is exemplified at Perranporth Beach where over a 7-day period, tide range can vary from 2 to 7 m between neap and spring tides. In conjunction with the template morphology and forcing wave conditions, tidal excursion controls wave breaking and rip activity. This significantly affects rip numbers and associated incidence, particularly within the low-tide bar and rip region (Figure 14.9a and b). At LTT+R and LTBR beaches, more incidents occur when the tide range is greater than the mean.

Field investigation at Perranporth (Austin et al., 2009) suggested that variations in rip activity can be expressed as down-state (neaps to springs) and up-state (springs to neaps) morphological transitions; this finding is similar to that observed by Brander (1999) using beach state descriptions of Wright and Short (1984), but as a function of tidal level controlling wave dissipation (Figure 14.10). At the MLWN level, the typical wave dissipation pattern represents a LBT/RBB system, and weak rip circulation with alongshore flows dominating. As tidal elevation decreases toward MLWS level, the wave dissipation pattern represents TBR morphology, and the combination of spatially variable wave dissipation and morphological constriction results in the strongest rip flows. During the lowest observed tides, the rip system became isolated, representing the TBR/LTT configuration. Within this model are two hazardous transitions: (1) falling tide from LBT/RBB to TBR (down-state) and (2) rising tide from LTT to TBR (up-state). The extent of tidal excursion during spring/neap cycles controls the extent of these transitions and hence the levels of low- and mid-tide rip activation.

Analysis of video images at Perranporth shows that changes in tidal range affect rip hazards on a daily basis. During a neap to spring tide transition, variations in tidal excursion from one day to the next were found to be sufficient for a rip current system to become active. This is particularly relevant if low-tide bar and rip morphology was well developed during the neap phase, but only becomes active during the subsequent spring phase. The assumption that rip current activity is closely associated with bar and rip morphology was tested at Perranporth using GPS drifters (Austin et al., 2009; Austin et al., 2010; Figure 14.11).

Rip circulation and flow speeds shown in Figure 14.11 were recorded when low energy swell waves, spring tides, and well-developed bar and rip morphology

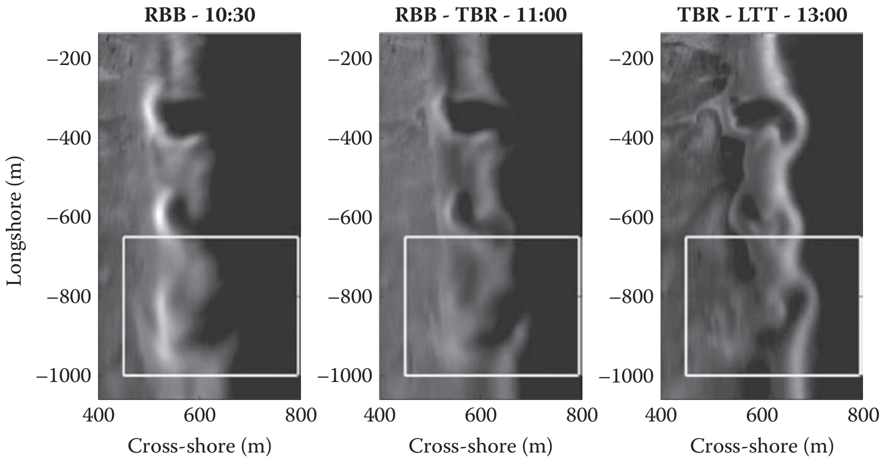

FIGURE 14.10 Time-averaged plan view video images of Perranporth Beach, west Cornwall, taken August 3, 2008 at the times indicated above panels (cross-shore distance increases to seaward). High pixel intensities (whiter regions) indicate high wave dissipation (breaking). Panels show progressive change in effective morphological beach state from RBB to TBR/LTT during falling tide. The highlighted boxes indicate the regions of GPS drifter deployment shown in Figure 14.11.

dominated. This indicates that rips can indeed switch on and off according to tidal elevation. Figure 14.11 shows all measured GPS drifter data classified into A_m/A_r bins representing degrees of morphological constraint on the rip flow. A_r is the cross-sectional area of the rip channel available for rip flow (increasing with tidal elevation), and A_m represents the morphologically constrained area of the channel (calculated at a water level where adjacent bars become exposed). A_m/A_r increases with decreasing tidal elevation as rip flow becomes increasingly channelized (Austin et al., 2010).

Currents recorded by the drifters were largely alongshore-dominated during higher tidal elevations associated with the RBB state in Figure 14.10. During the TBR and LLT stages, strongly rotational eddies constituted the principal circulation. Similar rotational circulation patterns were observed by MacMahan et al. (2010) within micro- and meso-tidal environments. This finding contradicts the long-standing notion of rip currents as seaward-flowing jets that expel bathers from the surf zone. In addition, alongshore-directed rip flows over the bar edge were of equal or greater speed than the offshore-flowing rip neck—an additional hazard. Under these conditions bathers standing on “safe” bar crests can be pulled laterally into a rip channel.

Tidal Translation (Semi-Diurnal Cycle)

Tidal translation is the rate of change in shoreline location and is key to developing high-risk conditions (Scott et al., 2009). While tidal excursion defines the extent of surf zone migration throughout the tidal cycle, tidal translation controls the rate of change of the tidal level and associated rip hazards. Many UK beaches have a

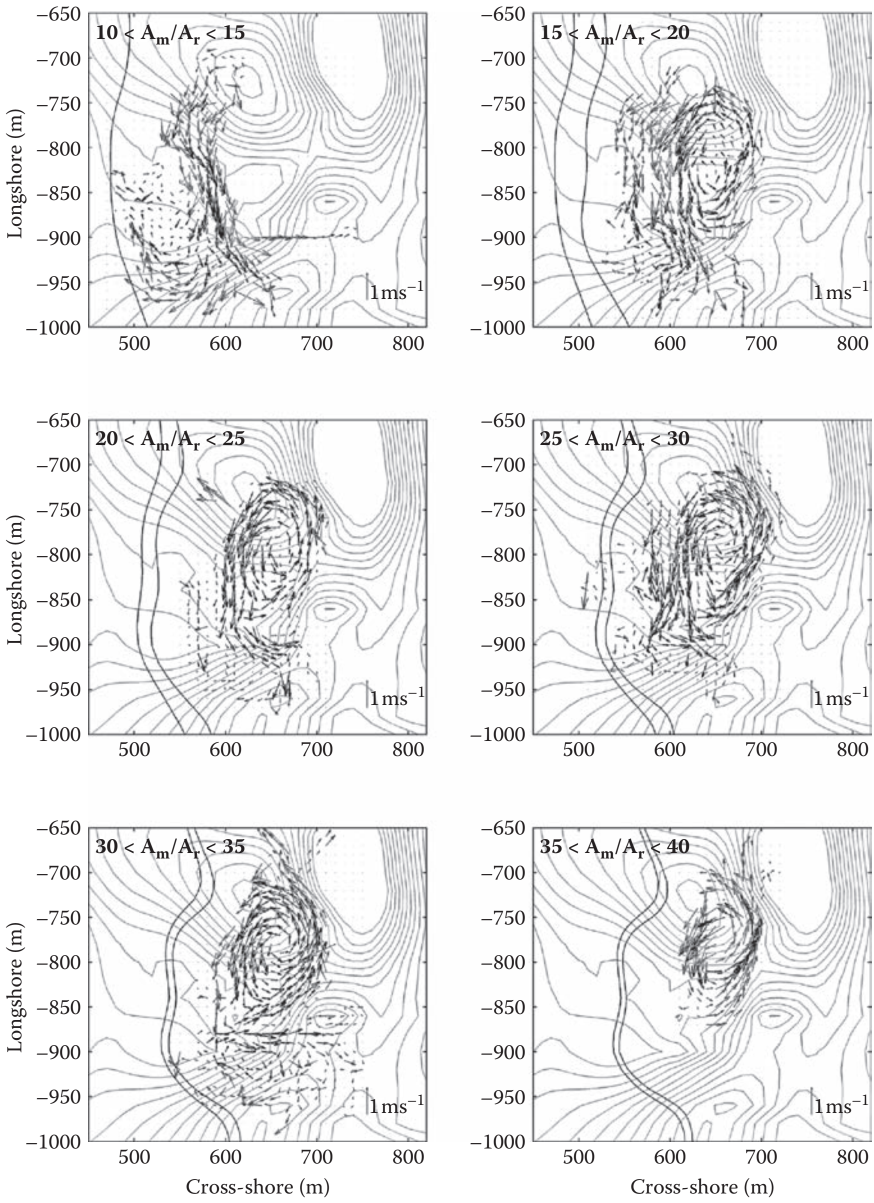

FIGURE 14.11 Mean Lagrangian GPS drifter circulation separated into classes defined by A_m/A_r that represent varying degrees of morphological constriction controlled by tidal level. Black vector arrows indicate rip speeds for bins classified as statistically significant (more than five independent observations). Gray arrows indicate all observations. Contours represent residual morphology. Black contours show approximate shoreline positional range for each bin. (*Source:* Austin, M., Scott, T., Brown, J. et al. 2010. *Cont. Shelf Res.,* 30: 1149–1165. With permission.)

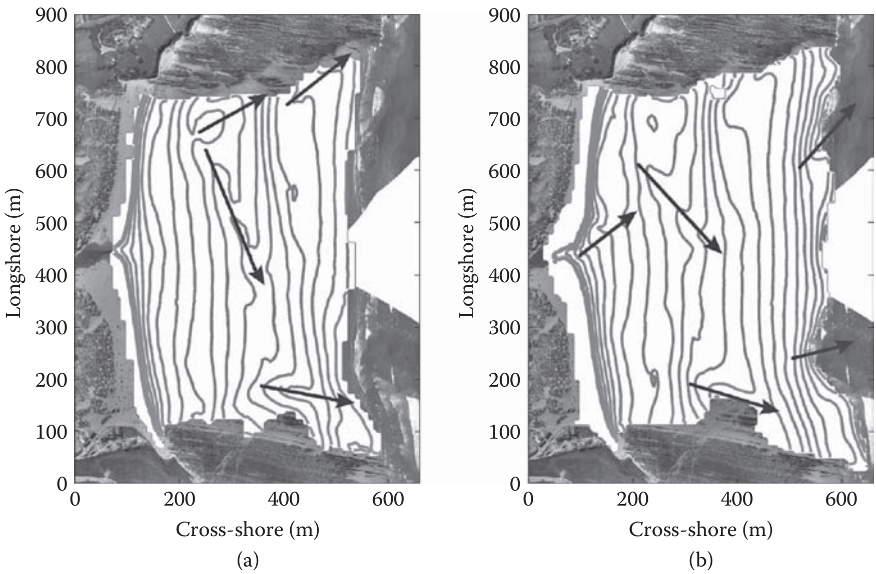

FIGURE 14.12 Fifteen-minute shoreline data (gray contours) from topographic surveys collected on spring tides on (a) June 18, 2007 and (b) September 14, 2007 at Croyde Bay, North Devon (*Source:* Scott, T.M., Russell, P.E., Masselink, G. et al. 2008. *Proc. Intl. Conf. on Coastal Engineering,* Hamburg, pp. 4250–4262.) Black arrows indicate regions of heightened rip current hazards during tides (*Sources:* Royal National Lifeboat Institution, Croyde Bay lifeguards, personal communication; background aerial images courtesy of Channel Coastal Observatory.)

tidal range >6 m with horizontal tidal excursions up to 600 m. For example, translation rates at Croyde Bay during large spring tides can reach 100 m in 15 min (Figure 14.12); this has significant implications for beach safety because of rapid alongshore migration of rips throughout the tidal cycle. In addition, large variations between spring and neap mean tidal excursion and translation can vary significantly on a daily basis.

HIGH-RISK SCENARIOS

Environmental factors as discussed above control the THS and combine to create high-risk scenarios that lead to mass rescue events as identified from lifeguard incident reports (Scott et al., 2009). During the 2007 patrol season, six mass rescue events occurred, significantly exceeding the coast-wide seasonal trend in *IR*. These events all involved more than 62 rip incidents in a single day (maximum of 151 per day) and more than 10 beaches simultaneously (maximum of 15). Examination of wave and tidal conditions as well as morphological state and beach population levels provides insight into key environmental conditions that cause high-risk situations for beach users.

Key Environmental Conditions

A number of key environmental conditions typically increase risk levels during periods of high-risk exposure (busy summer months):

- *Accretionary morphological conditions:* These conditions are observed on high-risk LTBR and LTT+R beaches with well-developed transverse bar systems; they evolve as a result of extended accretionary conditions during spring and summer months and are key elements in the creation of high rip risk levels for beachgoers.
- *Low- and medium-energy, long period swell waves:* Under these conditions often associated with summer accretionary periods, waves shoal on inner transverse bars during low- and mid-tides, generating strong alongshore variations in wave breaking and driving relatively strong rip flows. Rips that are morphologically constrained can have high flow speeds in relation to the forcing wave energy because of channelized flow between bars. These typical summer, low-energy conditions (H_s of 0.5 to 1 m; T_p of 6 to 12 sec) commonly occur in conjunction with high in-sea populations. These conditions allow greater bather activity in the surf zone, increasing exposure to rip current hazards.
- *Spring tides:* For macro-tidal regions, spring tidal periods are associated with increased rip incident risk through exposure of low-tide bars and rip current activation. Increased tidal excursion creates high tidal translation rates and hence rapid changes in rip hazards. The daily change of tidal range throughout the spring/neap cycle is also a significant control on the temporal hazard signature (THS) in macro-tidal regions where hazard levels change dramatically, even under similar wave conditions and beach morphology.

Practical Implications for Lifeguards

Mass rescue events are largely due to tidal changes that increase hazards for beach users. Tidal modulation of rip current circulation over well-developed bar morphology switches rips on and off through fluctuations in water levels. Tidal modulation of rips occurs at spring/neap (weekly) and semi-diurnal (daily) time scales. Complexity is added by intertidal transitions of rip locations both along- and cross-shore as tidal water levels change. These intertidal transitions can occur rapidly in macro-tidal environments and hazard exposure increases when the subsequent rip systems migrate alongshore, changing safe bathing areas into regions of rip activity. When this occurs, lifeguards must respond quickly by moving the designated bathing area laterally with the changing tide to regions of lower rip hazards.

Rip current circulation patterns are also modulated by tidal elevation. Strong alongshore flows can propel bathers from bar crests into rip channels. This is particularly problematic with large numbers of beach users. The circulatory nature of rips was observed, particularly during low tidal elevations, when only 10 to 20% of tracked drifters exited the surf zone. Instead of drifters being carried offshore into deep water, they circulated back over the bar—multiple times in some cases (Austin et al., 2010). Exposure of the low-tide bar crest during spring tidal conditions attracts bathers. During the subsequent flood, the bar crest rapidly submerges, and the feeder channel and rip system become active (TBR stage) as the in-sea beach user population passes through the feeder channel when trying to return to the beach.

Rapid changes in surf conditions due to high tidal translation rates require constant risk assessment and mitigation. Under certain combinations of events, the THS changes faster than reactionary mitigation measures can be implemented, resulting in coast-wide, mass rescue events.

The fundamental processes driving the complexities of rip currents (circulation patterns, flow speeds, and tidal modulation) are rarely well understood by even experienced lifeguards. With improved scientific understanding of surf zone processes and the temporal hazard signature, UK lifeguards will acquire the ability to provide more predictive and less reactive beach safety services.

CONCLUSIONS

This chapter discussed the nature of rip current hazards for large-tidal beaches in the UK. This work has shown that the temporal hazard signature, defined as the spatial and temporal variations in rip hazard characteristics, is controlled by a number of environmental factors. The combination of these factors creates high-risk scenarios that drive observed coast-wide mass rescue events. A basic scientific understanding of these mechanisms would equip lifeguards with additional knowledge required to improve risk mitigation during these high-risk scenarios.

Key Factors Controlling Rip Hazards

- *Beach type:* Characteristic beach morphology associated with different beach types is linked to the types and severities of expected rip current hazards. High rip hazards are associated with low tide terrace and rip (LTT+R) and low tide bar and rip (LTBR) beach types that commonly have low-tide bar and rip systems.
- *Seasonal beach change:* Intermediate LTT+R and LTBR beaches show significant seasonal changes in sand bar morphology from flat and featureless, erosive winter storm-dominated conditions to accretionary summer, swell-dominated conditions. During this transition, beach rip morphology commonly develops throughout the lower beach, increasing rip hazards with onset of the summer tourist season and warmer waters.
- *Waves:* Rip incident risk is highest during high-energy wave events that often occur in the early season when in-sea populations are low. High exposure of in-sea beach users (75%) during summer, low-energy, long-period wave conditions (H_s of 0.5 to 1.5 m) led to the highest number of rip incidents, illustrating the importance of understanding low- to medium-energy rip systems.
- *Tides:* Tidal modulation of water levels in large-tidal beaches exerts significant effects on exposure to rip hazards. Both the spring/neap and daily tidal cycles control the extent of tidal sweep (excursion) and the rate at which the

shoreline position changes (translation). These two factors control whether a rip current system becomes active at low-tide or not and also control the rates of change of rip hazards as the surf zone moves from one rip system to another as the tide floods and ebbs. The complex combination of these effects controls hazard levels over seasonal, fortnightly, and daily time scales.

REFERENCES

Aagaard, T., Greenwood, B., and Nielsen, J. 1997. Mean currents and sediment transport in a rip channel. *Marine Geol.,* 140: 25–45.

Austin, M., Scott, T., Brown, J. et al. 2010. Temporal observations of rip current circulation on a macro-tidal beach. *Cont. Shelf Res.,* 30: 1149–1165.

Austin, M.J., Scott, T.M., Brown, J.W. et al. 2009. Macrotidal rip current experiment: circulation and dynamics. *J. Coastal Res.*, 56: 24–28.

Bradbury, A.P., Mason, T.E., and Holt, M.W. 2004. Comparison of the Met Office UK Waters Wave Model with a network of shallow water moored buoy data. *Proc. 8th Intl. Workshop on Wave Hindcasting and Forecasting*, Hawaii.

Brander, R.W. 1999. Field observations on the morphodynamics evolution of a low-energy rip current system. *Marine Geol.*, 157: 199–217.

Brander, R.W. and Short, A.D. 2001. Flow kinematics of low-energy rip current systems. *J. Coastal Res.,* 17:468–481.

Clayton, K. and Shamoon, N. 1998. New approach to the relief of Great Britain II. A classification of rocks based on relative resistance to denudation. *Geomorphology*, 25: 155–171.

Davidson, M.A. and Turner, I.L. 2009. A behavioural-template beach profile model for predicting seasonal to interannual shoreline evolution. *J. Geophys. Res.,* 114: F01020.

Davies, J.L. 1980. *Geographical Variation in Coastal Development*. Longman, New York.

Dean, R.G. 1973. Heuristic models of sand transport in the surf zone. *Proc. 1st Austral. Conf. on Coastal Engineering, Engineering Dynamics in the Surf Zone,* pp. 208–214.

Department for Business Enterprise and Regulatory Reform. 2008. *Atlas of Marine Renewable Resources.* Technical Report R1342. ABP Marine Environmental Research Ltd.

Engle, J., MacMahan, J., Thieke, R.J. et al. 2002. Formulation of a rip current predictive index using rescue data. In *Proc. 15th Annu. Natl. Conf. on Beach Preservation Technology*, Tait, L., Ed., Florida Shore & Beach Preservation Association, Biloxi, MS, pp. 285–298.

Gourlay, M.R. 1968. *Beach and Dune Erosion Tests*. Report m935/m936, Delft Hydraulics Laboratory, Delft.

Guza, R.T. and Thornton, E.B. 1985. Observations of surf beat. *J. Geophys. Res.,* 90: 3161–3171.

Haller, M., Dalrymple, R., and Svendsen, I.A. 2002. Experimental study of nearshore dynamics on a barred beach with rip channels. *J. Geophys. Res.,* 107: 1–21.

Hartmann, D. 2006. Drowning and beach safety management along the Mediterranean beaches of Israel: a long-term perspective. *J. Coastal Res.,* 22: 1505–1514.

Jackson, D.W.T., Cooper, J.A.G., and del Rio, L. 2005. Geological control of beach morphodynamic state. *Marine Geol.*, 216: 297–314.

Lascody, R.L. 1998. East Central Florida rip current program. *Natl. Weather Dig.,* 22 :2.

Leahy, S., McLeod, K., and Short, A.D. 1996. *Beach Management Plan*. Surf Life Saving Australia Ltd., Sydney.

Lushine, J.B. 1991. A study of rip current drownings and related weather factors. *Natl. Weather Dig.,* 16: 13–19.

MacMahan, J., Brown, J.W., Reniers, A. et al. 2010. Mean Lagrangian flow behavior on a open coast rip channeled beach. *Marine Geol.,* 268: 1–15.

MacMahan, J.H., Thornton, E.B., and Reniers, A. 2006. Rip current review. *Coastal Eng.,* 53: 191–208.

MacMahan, J.H., Thornton, E.B., Stanton, T.P. et al. 2005. RIPEX: observations of a rip current system. *Marine Geol.,* 218: 113–134.

McNinch, J.E. 2004. Geologic control in the nearshore: shore-oblique sandbars and shoreline erosional hot spots, Mid-Atlantic Bight, USA. *Marine Geol.,* 211: 121–141.

Masselink, G. and Short, A.D. 1993. The effect of tide range on beach morphodynamics and morphology: a conceptual beach model. *J. Coastal Res.,* 9: 785–800.

McKenzie, P. 1958. Rip current systems. *J. Geol.,* 66: 103–113.

Scott, T.M., Russell, P.E., Masselink, G. et al. 2009. Rip current variability and hazard along a macrotidal coast. *J. Coastal Res.,* 56: 895–899.

Scott, T.M., Russell, P.E., Masselink, G. et al. 2008. High volume sediment transport and its implications for recreational beach risk. *Proc. Intl. Conf. on Coastal Engineering,* Hamburg, pp. 4250–4262.

Scott, T.M., Russell, P.E., Masselink, G. et al. 2007. Beach rescue statistics and their relation to nearshore morphology and hazards: a case study for southwest England. *J. Coastal Res.,* 50: 1–6.

Scott, T.M. 2009. Beach morphodynamics and associated hazards in the UK. PhD dissertation, University of Plymouth.

Shepard, F.P. 1949. Dangerous currents in the surf. *Phys. Today,* 2: 20–29.

Sherker, S., Brander, R., Finch, C. et al. 2008. Why Australia needs an effective national campaign to reduce coastal drowning. *J. Sci. Med. Sport,* 11: 81–83.

Short, A.D. 2006. Australian beach systems: nature and distribution. *J. Coastal Res.,* 22: 11–27.

Short, A.D. 2001. *Beaches of the Southern Australian Coast and Kangaroo Island: Australian Beach Safety and Management Project.* Sydney University Press, Sydney.

Short, A.D., Ed. 1999. *Handbook of Beach and Shoreface Morphodynamics*. John Wiley & Sons, New York.

Short, A.D. and R.W. Brander. 1999. Regional variations in rip density. *J. Coastal Res*., 15(3): 813–822.

Short, A.D. 1993. *Beaches of The New South Wales Coast: Australian Beach Safety and Management Project.* Sydney University Press, Sydney.

Short, A.D. and Hogan, C.L. 1994. Rip currents and beach hazards: their impact on public safety and implications for coastal management. *J. Coastal Res.,* 12: 197–209.

Short, A.D. 1985. Rip-current type, spacing and persistence, Narrabeen Beach, *Marine Geol*., 65(1–2): 47–71.

Sonu, C.J. 1972. Field observation of nearshore circulation and meandering currents. *J. Geophys. Res.,* 77: 3232.

Steers, J. 1960. *The Coast of England and Wales in Pictures.* Cambridge University Press, London.

Wright, L.D. and Short, A.D. 1984. Morphodynamic variability of surf zones and beaches: a synthesis. *Marine Geol.* 56: 93–118.