# Nearshore currents and swimmer safety

# in the Netherlands



M.Sc. Thesis

R.C. de Zeeuw

November 2011

TU Delft
Technische Universiteit Delft

Shore
Monitoring & Research

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M.Sc. Thesis

Roeland C. de Zeeuw, 2011

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Faculty of Civil Engineering and Geosciences
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# Preface

This thesis presents the final installment of the Master of Science program at the Faculty of Civil Engineering and Geosciences at Delft University of Technology (The Netherlands).

I thank my graduation committee prof. dr. ir. M.J.F. Stive, prof. dr. ir.J.A. Roelvink, dr. ir. G.J. de Boer, Ir. M. Henriquez and Ir. M.A. de Schipper for their input, support and guidance in the course of my graduation.

I thank the members of the HVRB for their time, cooperation and enthusiasm in participating in this research. Especially Joost de Graaf, Dennis Schouten, Marco de Jonge and Fred Bosman.
I also thank the members of the GVRB and especially Marcel Morauw for going through the rescue reports.

Martijn I specially thank you for all the times you sat down with me to create order in my chaos. To provide me with answers as to how and why certain things are done and need to be done. For encouraging me to endeavour on many, many techniques of for instance data filtering, only to find out, that ‘if it ain’t simple, it ain’t right’.

Matthieu, I am grateful to have had you as a supervisor, a teacher and at the same time as an associate. Thank you very much for your support, enthusiasm and infinite patience. Thank you for putting my thoughts and convictions in surprisingly other perspectives, forcing me to broaden my horizon on many aspects.

Furthermore, I thank the other guys Sierd, Chu, Brouwer, Joao, Wim and Menno for their company and shown interest during lunch and ‘bakkies’.

Thanks to all the people involved in the field campaign.

I also thank my friends for their support. And my family for repeatedly and consequently asking when I would finish.

And finally, I thank my girlfriend and soon to be mother of our child. No words can express what your presence means to me.

Roeland de Zeeuw

Den Haag, November 2011

# Summary

Artificial beach and foreshore nourishments as executed widely along the Dutch coast change the nearshore morphology and current patterns significantly. Over the last decades the size of the nourishments has increased from 0.7 x $10^6$ $m^3$/km to over 6 x $10^6$ $m^3$/km. Groynes which were present along the southern Holland coast since the 19th century are now (partly) covered with sand. As a result, entirely new dynamic coastlines and beach configurations are found at several locations along the southern Holland coast. This major impact on the beach configuration (disappearance of groynes, alongshore variations in shoreline amongst others) changes the currents swimmers and lifeguards were familiar with. This leads to uncertainty and concerns of lifeguards and (local) governments regarding swimmer safety, especially for the beach season after construction of the nourishment.

The 2010 nourishment of Scheveningen beach (one of the busiest beaches in the Netherlands) is an example of the creation of a new beach configuration. Photo I shows Scheveningen beach with groynes (pré nourishment 2010). Photo II shows the nourished beach of Scheveningen 2010. The coastline was shifted approximately 100 m seaward covering the groynes with sand. Concerns regarding the impact of the nourishment on swimmer safety arose at the municipality of The Hague.



**Photo I:** Scheveningen beach pré-nourishment 2009. Groynes present.



**Photo II:** Scheveningen beach nourishment 2010. Groynes covered by the nourishment.

One concern was a possible increase in longshore current due to the disappearance of the groynes. Secondly, the groynes along the Dutch coast are associated with many rescues of bathers. Bathers are caught in strong offshore directed currents invoked by the deflected alongshore currents at the upstream side of emerged groynes. These currents are called rip currents. Years of lifeguard experience with groynes ensured regular surveillance and adequate anticipation on rip currents near the groynes. The disappearance of the groynes would mean different occurrence of rip currents on the nourished beach. Not knowing when and where rip currents could be expected on the nourished beach, caused uncertainty and concerns towards the new beach season.

Rip currents are relatively fast flowing, concentrated, offshore directed currents, originating within the surf zone and often extending beyond it. On beaches all over the world, rip currents are responsible for many (near) drownings. They have especially gained (scientific) attention on swell dominated coasts (such as Australia, New Zealand, US). Little is known of rip currents along wind sea dominated coasts, such as the Dutch coast, where wind, wave and tidal driven alongshore currents frequently reach velocities of 1 m/s or more.

Two research objectives are formulated: 1) investigate the relevant aspects of nearshore currents and beach configurations with respect to swimmer safety and 2) investigate the regime for which rip currents are likely to form on a groyned and groyneless beach along the wind sea dominated South Holland coast.

A monitoring campaign of the beach season of 2010 in The Hague was initiated in cooperation with the lifeguards. Experiences and observations of the lifeguards with respect to swimmer safety on the groyned (unnourished) and groyneless (nourished) beach were discussed. Lifeguard reports of the rescue brigades of The Hague and 's Gravenzande (another rescue brigade on the frequently nourished Delfland Coast 13 km south of Scheveningen) were collected for a period of over 6 years to assess critical conditions and locations. Rescue research parameters (wind, waves, tide, temperature, cloud cover, precipitation amongst others) at times of the rescues were compared to seasonal occurrence of the parameters to investigate a causal relation between the parameters and swimmer safety.

Detailed lagrangian current measurements were performed on the groyned and groyneless (nourished) beach of Scheveningen, using GPS drifters. The measurements took place for a selected set of conditions, which, according to the analysis of the lifeguard rescue reports, caused many rescues in the past. Bottom topography of the nourished beach was surveyed just before or after the current measurements using PWC (jetski) surveys around high tide and low wave energy conditions. The sub aqueous surveys were complemented with RTK GPS 4wd- and walking surveys on the sub aerial beach around low tide, giving a coverage from -5 to +3 m above MSL. The acquired field data is analysed to identify hazardous currents, locations and to quantify the order of magnitude of the hazardous currents. The regime for the occurrence of rip currents along the open nourished beach and near groynes is investigated.

Commonly swimmer safety is associated with rip currents. On swell dominated coasts with large bottom topography variations in the nearshore and small longshore currents O(0.2 m/s), these rips can form a great risk for bathers. However, along the wind sea dominated Dutch coast with small vertical variations in bottom topography, frequent nourishments and combined tidal, wind and wave driven alongshore currents reaching 1 m/s or more, rips are found to be only one part of beach safety. In a synthesis of the analysis results seven aspects of nearshore currents and beach configuration were formulated, which need to be evaluated in order to make a comprehensive assessment of the impact of nearshore currents and beach configuration on swimmer safety at a certain location:

- Bars, troughs and channels
- Coastal structures
- Longshore currents
- Rip currents
- Predictability
- Profile gradients
- Alongshore coastline gradients

Critical conditions and locations were assessed, though no distinct causal relation between swimmer safety and hydro meteo conditions could be established, based on the performed analysis and available data. There are some combinations of hydro meteo conditions and locations that have caused more rescues than others. This is mainly due to the fact that some conditions prevail more often than others, resulting in a higher rescue count for these conditions. But partly also due to the combination of these conditions with the beach configuration and the associated presence of rip currents caused by these conditions. Side shore orientated conditions and low tide caused many rescues in rips near groynes. For the same conditions no rescues where performed on the open nourished beach. Conditions that did cause rescues on the open beach, where strongly onshore orientated: longer period near-normally incident waves and mild (offshore) wind conditions. These conditions also caused rescues on the beaches with groynes. But, as for all conditions that caused rescues, not all occurrences of these conditions caused rescues. This leaves a causal relation between hydro meteo conditions and swimmer safety hard to establish. It is recommended to investigate this causal relation through Bayesian modelling. This could reveal the dependencies of the variables involved. Most important missing data is related to the 'supply of swimmers to the sea' which should be monitored (amongst others).

Detailed lagrangian current measurements revealed a big difference in location and magnitude of maximum longshore current velocities along a groyned and open beach. Maximum current velocities O(1.3 m/s) along the open beach were measured close to the beach face diminishing towards the end of the surf zone, with a second local maximum O(0.5m/s) just on and offshore of the deepest part of the trough. This is contrary to the distribution of the longshore current along a beach with groynes, where maximum current velocities O(0.5 m/s) were observed towards the surf zone edge, diminishing in onshore direction.

The occurrence of rip currents on open beaches along the wind sea dominated South Holland coast was shown to be strongly related to and limited by the longshore current magnitude. Rip currents were observed when long- and cross shore current velocities were of the same order of magnitude, which was observed only for near-normally incident waves. No rip currents were observed when longshore current velocities were approximately three times higher than cross shore velocities, which was observerd for breaking wave angles of incidence larger than 10° to 15°. Wave angle of incidence, wave height, wave period, tidal level and vertical variations in bottom topography within the surf zone were identified as crucial factors in the occurrence of rip currents along the wind sea dominated Dutch coast.

Conceptual swimmer safety tools were presented for application by lifeguards on a groyned and open beach. Based on the above mentioned (and readily assessable) parameters the relative risk on rip currents can be estimated.

A second conceptual model was presented for coastal engineering purposes, in which the regime of the occurrence of rip currents along the Dutch coast can be evaluated in a quantitative way. It is recommended to evaluate the latter model using available field data of GPS surf zone drifters obtained at Vlugtenburg, the Sandengine and Egmond aan Zee.

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# 1 Introduction

## 1.1 Background

Artificial beach and foreshore nourishments as executed widely along the Dutch coast change the nearshore morphology and current patterns significantly. Over the last decades the size of the nourishments has increased from 0.7 x $10^6$ $m^3$/km to over 6 x $10^6$ $m^3$/km. Groynes which were present along the southern Holland coast since the 19th century are now (partly) covered with sand. As a result, entirely new dynamic coastlines and beach configurations are found at several locations along the southern Holland coast. This major impact on the beach configuration (disappearance of groynes, alongshore variations in shoreline amongst others) changes the currents swimmers and lifeguards were familiar with. This leads to uncertainty and concerns of lifeguards and (local) governments regarding swimmer safety, especially for the beach season after construction of the nourishment.

## 1.2 Scheveningen beach nourishment of 2010

The 2010 nourishment of Scheveningen beach (one of the busiest beaches in the Netherlands) is an example of the creation of a new beach configuration. Photo 1.1 shows Scheveningen beach with groynes (pré nourishment 2010). Photo 1.2 shows the nourished beach of Scheveningen 2010. The coastline was shifted approximately 100 m seaward covering the groynes with sand. Concerns regarding the impact of the nourishment on swimmer safety arose at the municipality of The Hague.



**Photo 1.1:** Scheveningen beach pré-nourishment 2009. Groynes present.

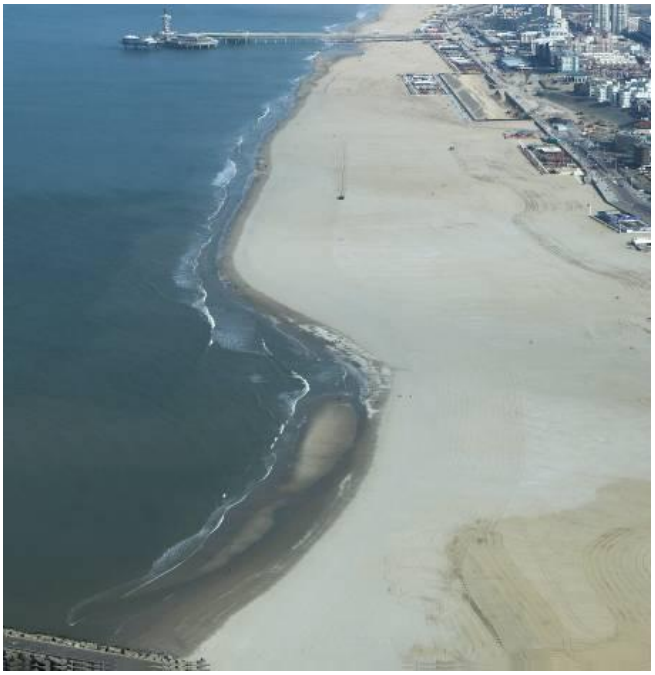


**Photo 1.2:** Scheveningen beach nourishment 2010. Groynes covered by the nourishment.

One concern was a possible increase in longshore current due to the disappearance of the groynes. Groynes were originally constructed to reduce erosion of the beach, by limiting sediment transport through deceleration of the longshore current. The decelerated longshore current in between the groynes often meant pleasant recreation and bathing for beach visitors.
Secondly, the groynes along the Dutch coast are associated with many rescues of bathers. Bathers are caught in strong offshore directed currents invoked by the deflected alongshore currents at the upstream side of emerged groynes. These currents are called rip currents. Years of lifeguard experience with groynes ensured regular surveillance and adequate anticipation on rip currents near the groynes. The disappearance of the groynes would mean different occurrence of rip currents on the nourished beach. Not knowing when and where rip currents could be expected on the nourished beach, caused uncertainty and concerns towards the new beach season.

Rip currents are relatively fast flowing, concentrated, offshore directed currents, originating within and often extending beyond the surf zone. Rip currents are responsible for many (near) drownings on beaches all over the world and have especially gained (scientific) attention on swell dominated coasts (such as Australia, New Zealand, US; e.g. MacMahan et al., 2009, 2006; Dalrymple et al., 2011; Brander, 1999; Lushine,1991; and references therein). Little is known of rip currents along wind sea dominated coasts, such as the

Dutch coast, where wind, wave and tidal driven alongshore currents frequently reach velocities of 1 m/s or more and swell waves are rare.

This thesis describes a research into relevant aspects of nearshore currents and beach configuration with respect to swimmer safety by evaluating the impact of the 2010 nourishment of Scheveningen on the current pattern and swimmer safety. Furthermore the occurrence of rip currents on the wind sea dominated coast of Scheveneningen is investigated through field measurements.

### 1.3 Research objectives and questions

Two research objectives are formulated:

1. Investigate the relevant aspects of nearshore currents and beach configurations with respect to swimmer safety
2. Investigate the regime for which rip currents are likely to form on a groyned and groyneless beach along the wind sea dominated South Holland coast.

The following research questions are formulated to meet the objectives:

- Which aspects of nearshore currents and beach configuration are relevant in the assessment of swimmer safety?
- What are attainable swimmer speeds, bather behaviour and hazardous scenarios for swimmers in general?
- Which conditions and locations along the beach have caused rescues in the past?
- Does a causal relation exists between swimmer safety and certain wave, weather and tidal conditions?
- When and where are rip currents likely to form? When is the current pattern predominantly longshore orientated?
- In which part of the nearshore and under which forcing can (strong) longshore currents be expected?
- In which part of the nearshore and under which forcing can (strong) cross shore currents be expected?

### 1.4 Approach

First, theory on nearshore currents, -morphology and beach configuration encountered along the Dutch coast was studied.

A monitoring campaign of the beach season of 2010 in The Hague was initiated in cooperation with the lifeguards. Experiences and observations of the lifeguards with respect to swimmer safety on the groyned (unnourished) and groyneless (nourished) beach were discussed.

Lifeguard reports of the rescue brigades of The Hague and ‘s Gravenzande (another rescue brigade on the frequently nourished Delfland Coast 13 km south of Scheveningen) were collected for a period of over 6 years to assess critical conditions and locations.
Rescue research parameters (wind, waves, tide, temperature amongst others) at times of the rescues were compared to seasonal occurrence of the parameters to investigate a causal relation between the parameters and swimmer safety.

Detailed lagrangian current measurements were performed on the groyned and groyneless (nourished) beach Scheveningen, using GPS drifters. The measurements took place for a selected set of conditions, which, according to the analysis of the lifeguard rescue reports, caused many rescues in the past. Bottom topography of the nourished beach was surveyed just before or after the current measurements using PWC (jetski) surveys around high tide and low wave energy conditions. The sub aqueous surveys were complemented with RTK GPS 4wd- and walking surveys on the sub aerial beach around low tide, giving a coverage from -5 to +3 m above MSL.

The acquired field data is analysed to identify hazardous currents and locations, the characteristics of the current pattern and used to quantify the order of magnitude of the hazardous currents. The regime for the occurrence of rip currents along the open nourished beach and near groynes is investigated.

Based on the preceding steps, criteria are formulated which are relevant to assess the swimmer safety on a beach with respect to nearshore currents and beach configuration. Furthermore, a conceptual diagram for the occurrence of rip currents and governing parameters is proposed for lifeguard use on a specific beach. Another diagram is proposed for coastal engineering purposes to gain more insight into the occurrence of rip currents and the relation between the governing parameters along the wind sea dominated Dutch coast.

### 1.5 Thesis Outline

Chapter 2 introduces theory on nearshore currents, swimmers speed and most commonly found beach configurations along the Dutch coast.

Chapter 3 describes the research into relevant swimmer safety aspects. The rescue brigades involved in this research are introduced. The monitoring of the beach season of 2010 in The Hague is described. Key observations are presented. The assessment of critical conditions and location based on lifeguard rescue reports is discussed. A causal relation between conditions and swimmer safety is investigated.

Chapter 4 is devoted to the description of the nearshore current and bathymetric measurements performed for specific conditions and beach configurations. The measurements are analysed to determine the impact of the nourishment on the nearshore current pattern. Hazardous currents and locations for swimmers are identified and their characteristics quantified. The regime for the occurrence of rip currents on the open nourished beach is investigated.

Chapter 5 is a synthesis of the results of Chapter 3 and 4. The relevant aspects of nearshore currents and beach configuration with respect to swimmer safety are formulated and discussed. Furthermore, a conceptual diagram for the occurrence of rip currents and governing parameters is proposed for lifeguard use on specific beach. Another diagram is proposed for coastal engineering purposes to gain more insight into the occurrence of rip currents and the relation between the governing parameters along the wind sea dominated Dutch coast.

Chapter 6 presents overall conclusions and recommendations.

# 2 Nearshore currents

## 2.1 Introduction

The area where most beach visitors on the Dutch coast swim or bath is called the surf zone. This is the area between the waterline and the 'line' where waves start breaking while approaching the beach. (Photo 2.1 blue arrow).



**Photo 2.1:** Indication of the surf zone by the blue arrow from the waterline towards first breaking point of the waves

Currents and bottom topography in the nearshore and more so within the surf zone vary in space and time depending on the forcing: wind, tide and waves. There are certain areas where concentrated offshore directed flows form: rip currents. Traditionally, rip currents are considered as most dangerous for swimmers and have been studied by numerous scientists since 1950, mainly for swell dominated coasts (such as the US, Australia, New Zealand). A comprehensive review of rip current systems was published by Dalrymple et al. (2011), but many other scientists have studied rip current forcing mechanisms, occurrence and coupling with underlying morphology as well (e.g. Shepard 1950, Bowen 1969, Brander 1999, 2000, Short 2000, Wright 1984, MacMahan 2009, 2010). For an extensive literature overview is referred to www.ripcurrents.noaa.gov/resources/rip_references3-04.pdf.

Rip currents on wind sea dominated coasts (such as the Dutch coast) have received less attention. Nevertheless, swimmers need to be rescued regularly by lifeguards along the Dutch coast. Not only because of rip currents, but also due to longshore currents which are frequently quite strong due to combined wave, wind and tidal forcing. To gain insight into when rip and longshore currents can become hazardous for swimmers and which hydrodynamic and meteorological conditions are causing them, available literature about the forcing phenomenon is studied. A brief description of the results will be given in the next paragraphs.

## 2.2 Longshore currents

Several physical phenomena can generate a current parallel to the shore:

- Tides
- Waves
- Wind

In this section expressions are formulated for the forcing and subsequent current velocity due to these phenomena based on literature.

*Tides*

The propagation of the tidal wave along the Dutch coast causes a longshore current. The forcing of the longshore current due to the tide for a certain location and tidal phase can be approximated by equating the water level gradient of the tidal wave to the bottom friction.

$$F_{tide,y} = \rho g h \frac{d\zeta}{dy}$$

In which:
$\zeta$ = water level w.r.t. MSL
$\rho$ = density of water
$h$ = waterdepth w.r.t. MSL

When the distance between two water level measurement locations is small compared to the tidal wavelength and the alongshore surface slope is assumed to be cross shore constant (due to the shore-perpendicular nature of the co-tidal lines) the water level gradient between these locations can be determined for every tidal phase (Ruessink et al., 2006). Generally, alongshore water level gradients due to the tide along the Dutch coast are in the order of 1 x $10^{-5}$. The dependence on water depth shows this force decreases with decreasing water depth (i.e. towards the shore). The magnitude of this force for Dutch conditions is in the order of 1 x $10^{-1}$ $N/mm^2$ in deeper water and 1 x $10^{-2}$ $N/mm^2$ in water depth of 1 m.

*Waves*
When waves arrive at the coast under an oblique angle a longshore current is generated. The generation of the current is commonly modelled by a momentum balance in which the cross shore gradient of longshore momentum flux due to the presence of waves is balanced by a bottom shear stress. A widely accepted concept for the horizontal excess momentum flux due to the presence of waves is called radiation stress (Longuet-Higgins Stewart, 1964, in Bosboom & Stive, 2010).

For a coordinate system with the positive x-axis perpendicular to the shore and y-axis parallel to the shore, it can be shown that for travelling waves in a direction $\Theta$ to the positive x-direction and using linear wave theory the radiation stress components are given by:

$$S_{xx} = \left\{n - \frac{1}{2} + ncos^2\Theta\right\}E$$

$$S_{yy} = \left\{n - \frac{1}{2} + nsin^2\Theta\right\}E$$

$$S_{xy} = S_{yx} = ncos\Theta sin\Theta\, E$$

Where $S_{xx}$ and $S_{yy}$ are the radiation normal stresses, $S_{xy}$ = $S_{yx}$ are the radiation shear stresses, $n$ is the ratio of the group speed over wave celerity and $E$ is the wave energy according to linear wave theory.

As mentioned above, horizontal gradients in radiation stress (momentum flux) give rise to net wave-induced forces in a particular direction. The net force in x- and y-direction is given by:

$$F_x = -\left\{\frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{dy}\right\}$$

$$F_y = -\left\{\frac{\partial S_{yy}}{\partial y} + \frac{\partial S_{yx}}{dx}\right\}$$

which for an alongshore uniform coast reduces to:

$$F_x = -\frac{dS_{xx}}{dx}$$

$$F_y = -\frac{dS_{yx}}{dx}$$

So the cross shore gradient of y-momentum flux in x-direction gives a net force in y-direction. This force can only be balanced by bed shear stresses due to a longshore current.

Assuming an alongshore uniform coast the wave angle changes in $x$ but not in $y$. Using Snell's law for regular waves ($sin\,\Theta/c$=constant) and conservation of energy ($d(Ec_g\,cos\,\Theta/dx = -D_w$) the momentum balance can be written as:

$$F_{waves,y} = F_y = -\frac{dS_{yx}}{dx} = -\frac{sin\theta}{c}\frac{d}{dx}\,Ec_g\,cos\theta = \frac{D_w}{c_0}\,sin\theta_0$$

So the driving force of the longshore current is a function of the dissipation of wave energy ($D_w$). In deep water outside the surf zone dissipation of wave energy can be neglected and hence the energy flux is constant, $S_{xy}$ = constant and $F_y = 0$ confining the longshore current to the surf zone.

Assuming a linear dependence between wave height and water depth in the surf zone provides a simple dissipation model. Combined with Snell's law, shallow water conditions and the assumption that due to refraction $\Theta$ is small this leads to:

$$F_{waves,y} = F_y = -\frac{5}{16}\frac{sin\theta_0}{c_0}\,\rho(gh)^{\frac{3}{2}}\gamma^2\,\frac{dh}{dx}$$

Consequently wave period, -height, -direction and profile gradient influence the force exerted on the water by breaking waves. The magnitude of this force is in the order of 1 x $10^1$ $N/m^2$ for obliquely breaking waves of approximately 1.5 $m$ with a period of 5.5 $s$.

*Wind*

Wind blowing over the water surface exerts a shear stress which causes the upper water layers to move approximately in the same direction. The current velocity profile over de water column generated by the wind shear stress differs largely from the logarithmic velocity distribution generated by a water level gradient. The highest flow velocity occurs at the water surface, rapidly decreasing with depth. A formulation for the wind shear stress in longshore direction is given by:

$$F_{wind,y} = \tau_{wind,y} = \rho_a c_d W_y \sqrt{W_x^2 + W_y^2}$$

in which:

$\rho_a$ is the density of air (1.25kg/m$^3$)
$C_d$ is a drag coefficient depending on wind velocity
$C_d = (0.63+0.066W)10^{-3}$ for $2<W<21$ m/s on the North Sea (Verlaan et al., 1993, in Bosboom & Stive, 2010)
$W_x$ = cross shore component of the wind velocity at the water surface
$W_y$ = longshore component of the wind velocity at the water surface
The magnitude of this force for Dutch conditions W = 10 m/s is in the order of 1 x $10^{-1}$ $N/m^2$

*Combined wind, waves and tidal forcing*

The resultant current velocity due to tidal, wave and wind forcing can be approximated by summing the consecutive forcings and equating it to a bottom shear stress balancing the total forcing.

$$\bar{\tau}_{b,combined,y} = F_{tide,y} + F_{waves,y} + F_{tide,y}$$

The formulation for the bed shear stress isn't trivial since the bed shear stress due to the wave orbital motion will change direction and magnitude within the wave period, while the bed shear stress due to the mean longshore current will be constant and parallel to the coast. Also turbulence due to the waves will be restricted to the boundary layer near the bed as opposed to the turbulence of a current over the entire water column. In addition to the assumptions already made in the above the time averaged bed friction vector will be related the depth average velocity vector which is the sum of the depth averaged longshore current velocity and the wave orbital motion:

$$\vec{u} = (\hat{u}\cos\omega t, V)$$

in which $\hat{u}\cos\omega t$ is the maximum cross shore orbital velocity due to waves and $V$ the depth-averaged longshore current velocity due to waves, wind and tide.

The time-averaged bed shear stress in longshore direction then becomes:

$$\bar{\tau}_{b,combined,y} = \rho c_f \overline{|\vec{u}|\vec{u}} = \rho c_f \overline{\sqrt{V^2 + \hat{u}^2 cos^2\omega t}V}$$

Assuming that the longshore velocity is much smaller than the maximum wave orbital motion this reduces to:

$$\bar{\tau}_{b,combined,y} = \frac{1}{\pi}\rho c_f \sqrt{gh}\frac{H}{h}V$$

Using

$$\bar{\tau}_{b,combined,y} = F_{tide,y} + F_{waves,y} + F_{tide,y}$$

This leads to the following expression for the longshore current velocity:

$$V = \left(\sum F\right) \frac{\pi\, h}{\rho c_f \sqrt{g h}\, H}$$

In the surf zone the wave driven current will dominate the current magnitude and direction, due to the difference in order of magnitude of the three forces and their dependence on water depth.

### 2.3 Rip currents

The concept of radiation stress as described in the previous section is also used to explain cross shore currents. However, in cross shore direction, gradients in radiation stress aren't balanced by a bottom shear stress but by the hydrostatic pressure gradients due to set-down and set-up of the mean water level.

$$\frac{dS_{xx}}{dx} = -\rho g(h+\eta)\frac{d\eta}{dx}$$

in which $\eta$ is the mean water level and $h$ the still water depth. When dissipation of wave energy well outside the surf zone can be neglected, the radiation stress component in cross shore direction is constant in deep water. Applying linear wave theory results in water level set-down just outside the surf zone due to shoaling, and set-up inside the surf zone due to dissipation of wave energy (e.g. Bowen, 1969). For an alongshore uniform beach and wave crests, the vertical imbalance between the cross shore pressure gradient and wave forcing results in an offshore directed flow within the surf zone between the bed and wave trough. This is often called undertow and commonly (in media) confused with rip currents. The magnitude of the set-down and set-up for a linearly sloping beach and constant ratio of breaker height over depth are given by $-\frac{1}{16}\gamma H_b$ and $\frac{5}{16}\gamma H_b$ respectively.

When alongshore variation in wave breaker height exists, either due to vertical variations in bottom topography within the surf zone or due to wave-wave interactions, differences in water level setup and set down are introduced in the surf zone and consequently water level gradients in alongshore direction. This is when rip currents can be generated. Due to these alongshore water level gradients, currents are generated towards areas of lower water level setup. These currents are called the feeder currents. They converge in areas of lowest water level setup: most often the deeper parts in the surf zone (where no waves are breaking), and form concentrated offshore directed currents: rip currents. This is schematically shown in Figure 2.1. The rip current itself is often called the rip neck. When it punches through the breaker zone, it diffuses. This part is called the rip head.

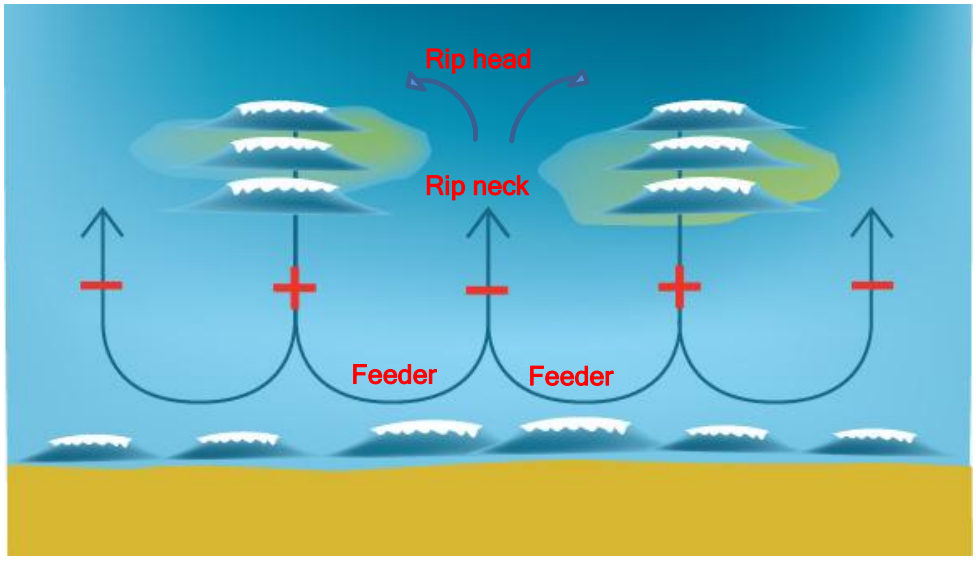



**Figure 2.1:** Schematised current pattern on a beach with alongshore trough and bars incised with rip channels. + and - signify large and small water level set up due to wave breaking. Elements of rip current system indicated.

Dalrymple et al. (2011) has published an extensive overview of the variety of rip currents, the beaches they occur on and mechanisms which cause them. Typically distinction is made between topographically controlled rips and transient rips. The topographically controlled rips appear in many forms and are coupled to the underlying bottom topography. Whether they occur, is dependent on wave

characteristics, tidal level, beach state (Wright et al., 1984), scale of the variations in bottom topography and geographic configuration of the beach. Intermediate beach states are believed to be most prone to rip current formation. On the alongshore bar-trough beach with incised rip channels (LBT), rhythmic bar and beach (RBB) and the transverse bar and rip beach (TBR), shown in Figure 2.2, rip channels and bars are more pronounced than on purely dissipative or purely reflective beaches. The alongshore variations in wave breaking due to the variations in bottom topography cause rip currents in the channels or depressions in the bars as indicated by the sketches depicted on the right side of Figure 2.2 (LBT', RBB', TBR').

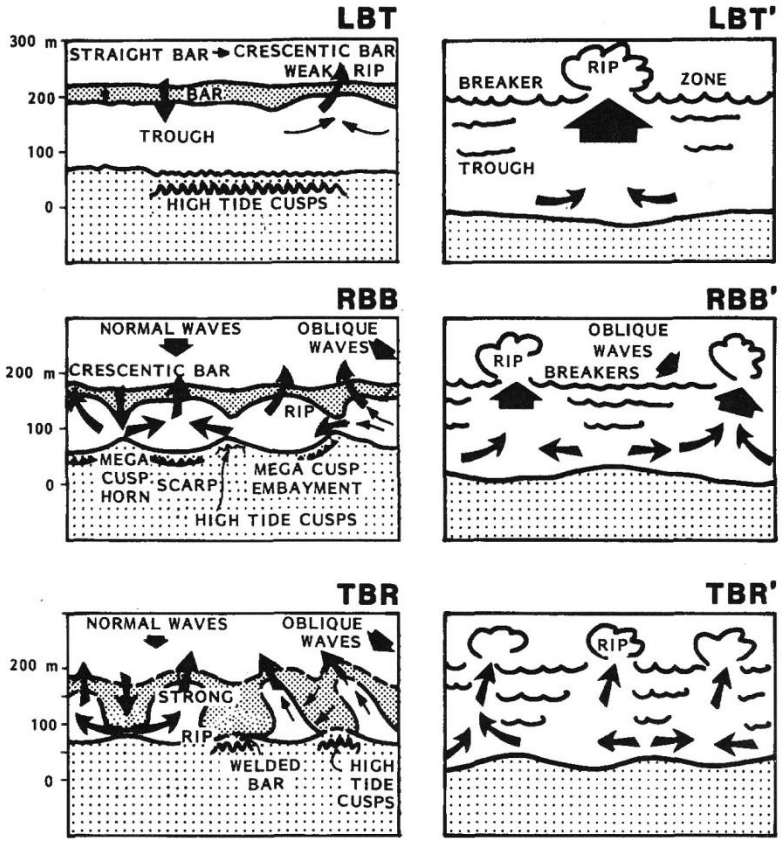



**Figure 2.2:** Intermediate beach states according to Wright and Short (1984). Longshore bar trough (LBT), rhythmic bar beach (RBB), transverse bar rip and associated schematised rip currents (LBT', RBB', TBR'). (source: Wright and Short, 1984)

The transient rip currents are often weaker, episodic and tend to migrate along the beach. The occur commonly on open-coast beaches under oblique wave incidence. Contrary to the morphologically controlled rips, they migrate freely along the beach.

Figure 2.3 shows the overview of different rip currents according to Dalrymple et al. (2011). Figure 2.3a is an example of a longshore bar-trough beach incised with a rip channel. Figure 2.3b shows a transverse bar rip system with large variations in bottom topography. Figure 2.3c shows rips near coastal structures. Figure 2.3d is an example of a mega rip. Due to the geographic configuration and large swell waves approaching this beach, a mega rip is formed in the middle of the embayment. This is the biggest form of rip currents, where entire beaches form the rip current system, instead of the bars and channels on the open coast beaches. Figure 2.3e is a special kind of rip, associated with wave run up processes on steep reflective beaches. These are called swash rips. The transient rips are schematically shown in Figure 2.3f-g.

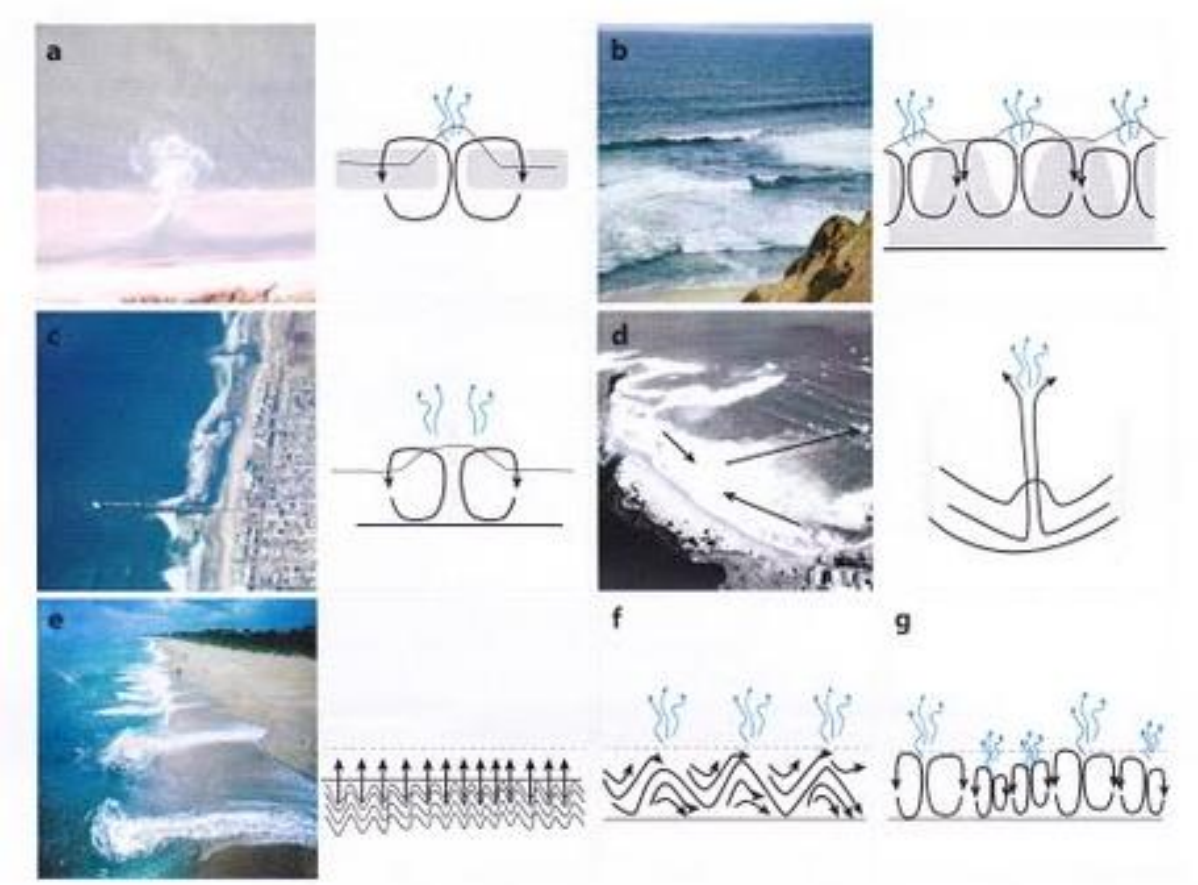



**Figure 2.3a-g:** Examples of rip current systems. a) longshore bar trough beach with rip channel; b) transverse bar rip system; c) rips near structures; d) mega rip system in embayed/ pocket beach; e) swash rip systems; f) transient rip due to obliquely incident waves; g) transient rips due to near-normally incident waves. (source: Dalrymple et al., 2011).

Wave breaking is an important factor in the occurrence of rips. The tide influences water level and consequently the locations of wave breaking. Most often rip currents are observed when waves break on the bar, instead of offshore or on the beach face. For most intermediate beaches this is around the low to mid tide period. When the tidal level falls bottom topography effects become more pronounced and flow is restricted more to the channels in between the bars. Higher water levels cause the waves to shoals over the bar and break on the shore (Dalrymple et al., 2011 and references therein)

Besides the tidal influence numerous studies have been performed to investigate the pulsations of rips currents. Very low frequency motions and shear instabilities of the rip moving into deeper water outside the surf zone are believed to be responsible for this.

### 2.4 Rips as swimmer safety hazard

Rip currents are widely held responsible for many (near) drownings on beaches worldwide. Lushine (1991) and Lascody (1998) have performed studies on rip current related incidents and fatalities in the USA. It was indicated that 80% of the lifeguard rescues in Florida, USA were rip current related. Lushine(1991) developed a rip risk forecasting tool (LURCS) based on wind velocity and direction, tidal variations, swell wave heights and a persistence factor. Different factors were summed, indicating the risk on rips. This was later altered by Lascody(1998) to the ECFL LURCS, by changing the tidal factor and including swell period. Mainly onshore directed winds, low tide and swell waves were correlated to rip current incidents. Engle et al. (2002) and Gensini et al. (2009) developed this system further by including social, meteorological, geographical aspects an improved tidal factor and most important included wave direction. In Australia Short and Hogan (1994) used wave height and beach state to indicate the risk on rips, no wave direction is included. For increasing wave height increasing rip risk is indicated.

These systems generally give a higher risk on rips for small wave angles (if included in the system) intermediate beach states and longer period (>8s waves). For the wind sea dominated Dutch coast little studies into the occurrence of rip currents have been performed. Strong wind, wave and tidal driven alongshore currents prevail the greater part of the time and swell waves with periods >8 s (typical periods for which the above mentioned risk systems begin to indicate risks) occur very seldom. Still every year people drown or

need to be rescued out of rip currents. The next section will describe the main rip currents systems as encountered along the Dutch coast.

## 2.5 Rip currents systems encountered along the Dutch coast

There are three main types of rip current systems encountered along the Dutch coast:

- Permanent rips near emerged impermeable coastal structures such as groynes and harbour jetties
- Topographically controlled rips in channels or depressions in the breaker bar.
- Flash rips

### *2.5.1 Permanent rip currents*

Traditionally the groynes with a crest level at approximately MSL deflect wave and tidal alongshore currents in the low tide period and invoke a strong outward flowing current. Photo 2.2 shows an example of a groyned beach. The current pattern on a beach with emerged groynes shows permanent rips at the upstream side of the groyne due to any longshore current and possibly eddies in the lee side of the groynes (Figure. 2.4). The thickness of the lines in Figure 2.4 indicates the relative current velocities. A positive effect caused by the groynes is the relative calm area in between the groynes (A). Offshore from the groynes the longshore current is stronger (B). This is an example of a tidal longshore current invoking rips. That is often omitted in the rip risk forecasting systems as discussed in the previous sections.



**Photo 2.2:** Picture of groynes beach around low tide. (source: www.kustfoto.nl)

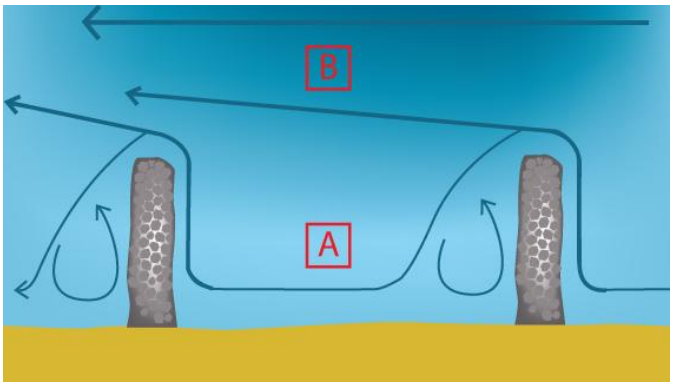



**Figure 2.4:** Schematised current pattern near groynes due to any longshore current. Negative impact for swimmers: rips on the upstream side, possible eddies in the lee side of the groynes. Positive impact for swimmers: longshore current velocity in between the groynes (A) is smaller than offshore of the groynes (B).

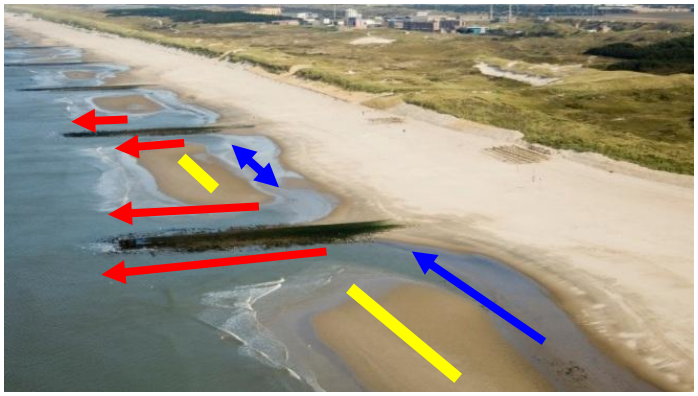


**Photo 2.3:** Example of permanent rips (red arrows) next to groynes. Breaker bar (yellow line) and trough/feeder current (blue arrows) are clearly visible. (source: www.kustfoto.nl)

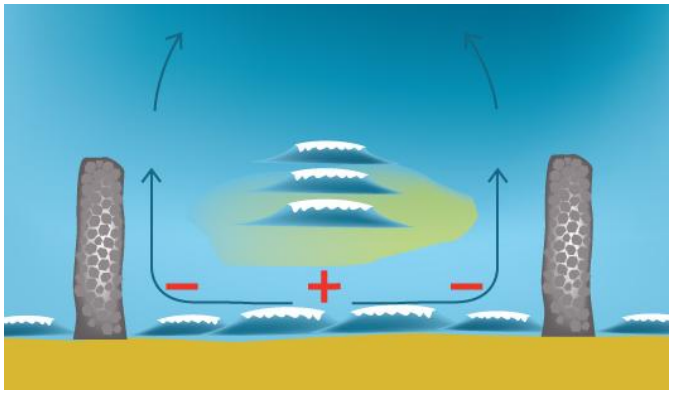



**Figure 2.5:** Schematised current pattern under normally incident waves over submerged breaker in between groynes due to water level setup gradients as indicated by + and - signs.

Photo 2.3 shows the pronounced morphology as often encountered between the groynes. One or two sandbars are often present in between the groynes (yellow bar). Note the deeper troughs (blue) and channels (red), which are very distinct. The associated current pattern due to normal incident wave breaking over the (submerged) bar is schematically indicated in Figure 2.5. In case of normally incident waves there is some wave breaking directly on top of the groyne, almost no wave breaking in the deep areas next to the groyne and intense wave breaking over the bar(s). The set up in water level increases with increasing wave breaking. Consequently, there is a gradient in water level between the area behind the bar(s) and channels. This causes a current towards the channel: the feeder current. The rip currents are stronger with increasing wave breaking over the bar. Besides the gradient in water level, mass flux by the non-linearity and breaking of waves causes a net onshore directed flow over the bar. Since it can't pile up on the beach it flows along the bar into the channel, enhancing the rip circulation. Generally, a combination of both current patterns will develop, depending on the conditions.

*2.5.2 Topographically controlled rip currents*

The second type of rip currents found along the Dutch coast are the topographically controlled rips. They are formed by channels and depressions in the breaker bars. The rips are fixed to the channels and depressions in the sandbars. But the channels and bars can migrate freely along the beach. Photo 2.4 shows an example of such rips. Several breaker bars (yellow lines), troughs (blue arrows) and channels are visible. The schematised current pattern is shown again in Figure 2.6. The same processes as discussed in the previous section are active, with the exception that there are no rigid boundaries. The topographically controlled rip systems are found in many different sizes as discussed in section 2.3. The different widths of the channels through the bars is clearly visible in Photo 2.4. The thin red arrow indicates a small channel O(10 m), the big red arrow a large channel O(100 m).

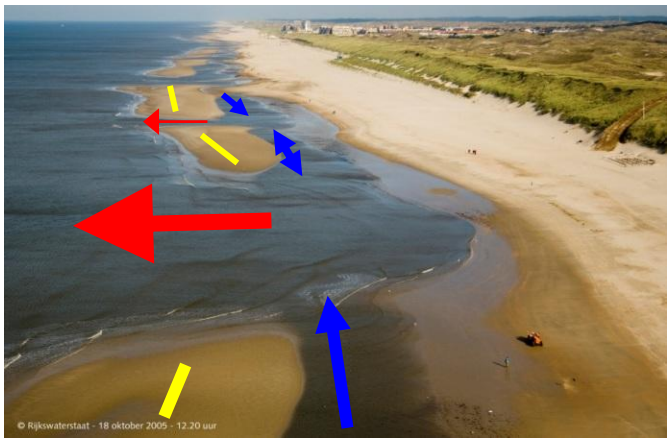



**Photo 2.4:** Example of a topographically controlled rip current system. Red arrow indicates rip, yellow the sandbars and blue the troughs and consequent feeder currents. (source: www.kustfoto.nl)

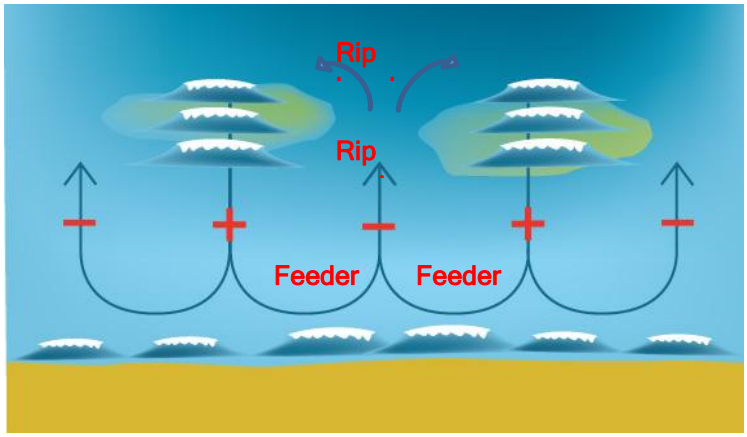



**Figure 2.6:** Schematised current pattern on a beach with alongshore trough and bars incised with rip channels. + and - signify differences in water level set up due to wave breaking. Elements of rip current system indicated.



**Photo 2.5:** Small rip on the beach (thin arrow), leading towards the deeper trough between the beach and the first breaker bar. In the right bottom corner a rip channel is visible in the first breaker bar. (source: www.kustfoto.nl)



**Photo 2.6:** Example of a flash rip. (source: www.muien.nl)

A small topographically controlled rip can be observed in Photo 2.5. Trapped water in the shallow troughs on the beach that only flood during high tide, flows through the swash back into the surf zone. These rips are only a few decimetres deep, but can get quit strong. Their width is often just a few meters. Because of their shallowness they are only a threat to small children. These small rip channels can form bigger rips at high tide at times of considerable surf and are often experienced by surfers.

*2.5.3 Flash rip currents*

In case of high surf short strong rips can form spontaneously. They form in an instant and typically only last for a few minutes (max). There is no immediate link with bathymetric features. Most often they are experienced by surfers, immediately behind the surf zone. A flash rip is most effectively spotted by the white water flowing offshore through the breakers (Photo 2.6), whereas the other types of rips are characterised by (narrower) darker patches of water in between the breakers.

## 2.6 Swimmer velocities

Common morphology, beach configurations and theoretical currents patterns encountered along the Dutch coast have been described. Whether a current is hazardous for swimmers greatly depends on current velocity, direction, water depth and for an important part on the velocity a swimmer can attain and maintain for a certain period of time. The only information on swimmer speeds was deducted from cooper tests held in swimming pools for swimmers of different physical ability, age and gender. The total distance swum in 12 minutes is registered. Dividing the total swimming distance by the elapsed time, gives an idea of swimmer speeds in confined, calm water that can be maintained for 12 minutes. Table 2.1 shows the average swimmer speeds for such a cooper test.

**Table 2.1:** Average swimmer speed in m/s for different age groups and fysical ability ratings maintained over 12 minutes in a swimming pool. (M = Male, V = Female). (source: www.muien.nl)

| Physical ability rating | | Age group | | | | |
|---|---|---|---|---|---|---|
| | | 13-19 | 20-29 | 30-39 | 40-49 | 50-59 |
| | | Swimmer speed in m/s | | | | |
| 1. Very poor | M | <0,7 | < 0,6 | < 0,49 | < 0,4 | < 0,35 |
| | V | < 0,6 | < 0,4 | < 0,35 | < 0,28 | < 0,21 |
| 2. Poor | M | 0,7-0,8 | 0,56-0,69 | 0,49-0,62 | 0,42-0,55 | 0,35-0,48 |
| | V | 0,56-0,69 | 0,42-0,55 | 0,35-0,48 | 0,28-0,42 | 0,21-0,35 |
| 3. Average | M | 0,83-0,97 | 0,7-0,8 | 0,62-0,76 | 0,56-0,69 | 0,49-0,62 |
| | V | 0,7-0,8 | 0,56-0,69 | 0,49-0,62 | 0,42-0,55 | 0,35-0,48 |
| 4. Good | M | 0,97-1,11 | 0,83-0,97 | 0,76-0,9 | 0,7-0,83 | 0,62-549 |
| | V | 0,83-0,97 | 0,7-0,83 | 0,62-0,76 | 0,56-0,69 | 0,49-0,62 |
| 5. Excellent | M | > 1,11 | > 0,97 | > 0,9 | > 0,83 | > 0,76 |
| | V | > 0,97 | > 0,83 | > 0,76 | > 0,7 | > 0,63 |

It must be emphasized that above velocities are merely an indication of swimmer speeds in calm water. When caught in a hazardous current in the sea, stress, cold and panic will decrease the attainable swimmer speeds, and certainly influence the amount of time swimmers can maintain that speed. **Therefore current velocities higher than 0.25 m/s will be classified as potentially dangerous to swimmers. When such current velocities are combined with chest deep or deeper water the situation becomes more dangerous.**

Nearshore currents, morphology, beach configurations encountered along the Dutch coast and swimmer speed were described. The next chapter will present the results of an investigation into swimmer safety, potential dangerous conditions and locations and whether a causal relation exists between hazardous currents and certain wave, weather and tidal conditions.

# 3 Swimmer safety and rescue brigades in the Netherlands

## 3.1 Introduction

This chapter is devoted to the investigation intro relevant aspects of nearshore currents and beach configuration with respect to swimmer safety. A great source of information regarding swimmer safety are the rescue brigades. They patrol large stretches of beach during the beach season, observing the beach, currents and bathers. Moreover, they keep record of the rescues they perform.
The rescue brigade of The Hague (HVRB) and 's Gravenzande (GVRB) have been involved in this research to reveal hazardous scenarios for swimmers (amongst others) and obtain their view on swimmer safety aspects in relation to nearshore currents and beach configuration. A monitoring campaign of the beach season of 2010 in the Hague was initiated in cooperation with the lifeguards of the HVRB, to obtain their experiences with respect to the changes of the beach configuration after the 2010 nourishment of Scheveningen beach. Section 3.3 describes the approach and results of the monitoring. Section 3.4 describes how the rescue reports of both rescue brigades were used to assess critical conditions and locations on the groyned and nourished (now groyneless) beaches. Furthermore, a causal relation between swimmer safety and specific conditions is investigated. Section 3.5 presents the results of the statistical analysis of the reports and investigation into a causal relation between rescues and specific wave, weather and tidal conditions. Overall conclusions are presented in section 3.6. But first, the rescue brigades are introduced.

## 3.2 Rescue brigades

Rescue brigades along the Dutch coast are organisations of volunteers, which dedicate a great part of their free time to watch over (bathing) beach visitors. They patrol large stretches of the Dutch coast during the beach season, which runs approximately from the 15$^{th}$ of May to the 15$^{th}$ of September. They observe the beach, currents and bathers and keep record of the rescues they perform. Every rescue brigade sets its own policy according to their views on swimmer safety and management, which are for a great deal based on experience with the local situation. The knowledge of the rescue brigades regarding the occurrence and characteristics of hazardous currents is also experience based.

In the introduction of this thesis it was already mentioned that beach and shoreface nourishments executed along the Dutch coast are growing in size. As a result of this, beach configurations have changed drastically at some beaches along the South Holland coast. At these places, swimmer safety management and rescue strategy based on past experience are less applicable to the new situation. Scheveningen (The Hague) and Vlugtenburg ('s Gravenzande) are two beaches that have experienced such drastic changes in beach configuration. Therefore they have been selected for this research. The two sites will be introduced shortly.

### *3.2.1 Scheveningen (HVRB)*

Photo 3.1 and 3.2 present the main beach of The Hague (Scheveningen) before and after the nourishment of 2010 respectively. The nourishment covered the groynes (numbered for geographic reference) with sand. Alongshore gradients are introduced at the lateral boundaries of the nourishment (Photo 3.2).




**Photo 3.1:** Beach of Scheveningen pré-nourishment 2009. Groynes 42-45 visible. (source: www.kustfoto.nl)




**Photo 3.2:** Nourished beach of Scheveningen 2010. Groynes 42-44 covered by the nourishment, 45 still present. Arrows indicate lateral boundaries of the nourishment. (source: projectbureau Combinatie Delftlandse Kust)




**Figure 3.1:** Range of rescue brigade of 's Gravenzande (GVRB, green), neighboring towns and range of HVRB (yellow) (source: google earth)

*3.2.2 Vlugtenburg (GVRB)*

Vlugtenburg is the second site selected for this research. A new beach configuration was created by the dune compensation, beach and foreshore nourishments of 2008 and 2009 at the Delfland Coast. An entire new dune row and dune valley were constructed. Photo 3.3 shows the execution of the nourishment and the original dune, beach and coastline with groynes. Photo 3.4 is a zoom-in on the northern part of the construction, showing the groynes more clearly. The coastline was shifted several hundreds of meters seawards covering the groynes with sand.




**Photo 3.3:** Construction of the dune compensation and beach nourishment at Vlugtenburg in 2008 and 2009. Original dunes and beach with groynes indicated with black arrows. Location of new dune row, -valley and beach under construction (indicated in white text). (source: www.delflandsekust.nl)




**Photo 3.4:** Construction of the dune compensation and beach nourishment at Vlugtenburg in 2008 and 2009. Zoom in on groynes. (source: www.delflandsekust.nl)

The base of the rescue brigade of 's Gravenzande ('s **G**ravenzandse **V**rijwillige **R**eddings**B**rigade) is the beach of Vlugtenburg, near the town 's Gravenzande. When needed the GVRB assists neighbouring beaches as well. They roughly cover an area from the south of Ter Heijde, to the north of Hoek van Holland, as shown in Figure 3.1. The greater part of information of the GVRB used for this research is obtained through their rescue reports and accompanying comments. The reports could provide insight in the amount of rescues on a groyned beach and on a nourished (groyneless) beach.

All parts of the coastline between Hoek van Holland and The Hague have been nourished over the years. Hoek van Holland has been nourished several times (2004 and 2008). The dune compensation at Vlugtenburg was carried out in 2008 and 2009. During the winter of 2009 the groynes at Ter Heijde and Kijkduin disappeared under a nourishment as well.

The next section will describe the monitoring campaign of the beach season of 2010 in the Hague.

### 3.3 Monitoring Scheveningen beach summer 2010

Traditionally, swimmer safety is associated with rip currents. To reveal whether there are other relevant swimmer safety aspects a monitoring campaign of the beach season of 2010 in The Hague was set up with the HVRB. Lifeguards were interviewed to obtain their observations and experiences with respect to swimmer safety issues on the nourished and unnourished beaches. Secondly, lifeguards could report observations and rescues online, during the beach season. These filed reports were discussed in weekly visits to the HVRB posts on the beach and included in the analysis of the rescue reports to assess critical conditions and locations.

The lifeguards were asked to give their view on:

- general bather and beach visitor behaviour
- hazardous currents and locations on the old and new beach
- wave, weather and tidal conditions that almost certainly cause rescues (trouble for bathers) according to them
- impact of the new beach configuration on nearshore currents
- the (new) beach configuration; e.g. profile, sandbars, troughs, scarps etc.
- the impact of the new beach configuration on their work

Their observations and remarks are quoted in the blue textboxes below.

Bather behaviour

There are roughly **two types of bathers**: **locals** who are familiar with the beach and sea, **and the rest** (people from inland, tourists).

Biggest problems are caused by people that aren't familiar with the local situation. Arriving at the beach, they don't pay attention to (warning) signs or flags. They just want to get into the water, straight in front of where they arrived at the beach. Often the North Sea looks relatively calm. Even when they are bad swimmers, they think it's safe to go into the water. Sometimes complete groups of tourists need to be rescued or warned and sent away to different parts of the beach.

The lifeguards emphasize that a very important and often detrimental factor is **panic**:

**Bathers panic when they notice that they're being taken away from their reference point** (often their own towel) further than they like. This doesn't need to be perpendicular to the coast. Strong longshore currents can have the same effect on swimmers as rip currents. Instead of anticipating on the current direction, they start swimming back to their reference, often against the current. When they notice they're not getting closer, the panic gets worse. **Exhaustion** is now just as big an enemy as the current itself. It is a matter of time before they start taking in water and really get into trouble if nobody comes to their rescue…

Crowded days aren't necessarily busy days for the lifeguards:

When the beach is crowded with visitors, the chance of people getting into trouble is bigger, but there is also a kind of social control. Other bathers help the ones in trouble. On days with less crowds, but still people (mainly tourists) on the beach that want to swim anyway regardless of the weather (because they are on holiday at the beach), we can have just as much work as on the crowded days.

Hazardous currents and locations on the groyned beach

A very common hazardous situation for bathers on the groyned beach is a rip current near the groynes, illustrated by Figure 3.2.

**The groynes are the place where most rescues take place.** During the low water period, they are emerged from the water. The rip currents along the sides of the groynes are almost always present. It's a lot deeper along the sides of the groynes, so people can't touch the bottom and the current is often too strong to swim up against. When bathers in the rip current see the stones of the groynes passing by in the wrong direction, they panic. Usually we try to guide them around the groyne. Sometimes we help them get on to the groyne at the tip. If the victim is panicking or in need of assistance we start a rescue.

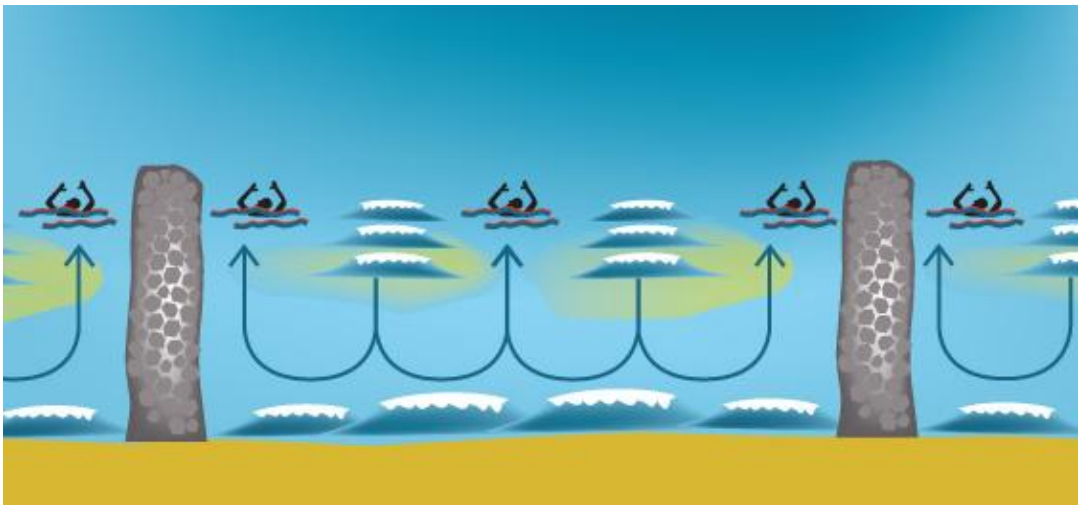


**Figure 3.2:** Illustration of rip current near groynes and swimmer in hazardous situation and in need of help.

This is certainly not the only type of hazardous current as illustrated by Figure 3.3.

Around high water the groynes are submerged in the water. The rip currents seem to disappear or weaken. If the **current along the shore is fairly strong** it can drag bathers over the groynes. People that are aware of the groynes either calmly float over them and nothing happens to them. Or they try to swim away from them, against the current. They often can't beat the current and touch the groynes or are being dragged over. Panic, cuts and bruises are the result.

The current along the harbour jetty, can also cause troubles for bathers. Sometimes, also surfers who aren't familiar with the rip along the jetty need to be rescued.

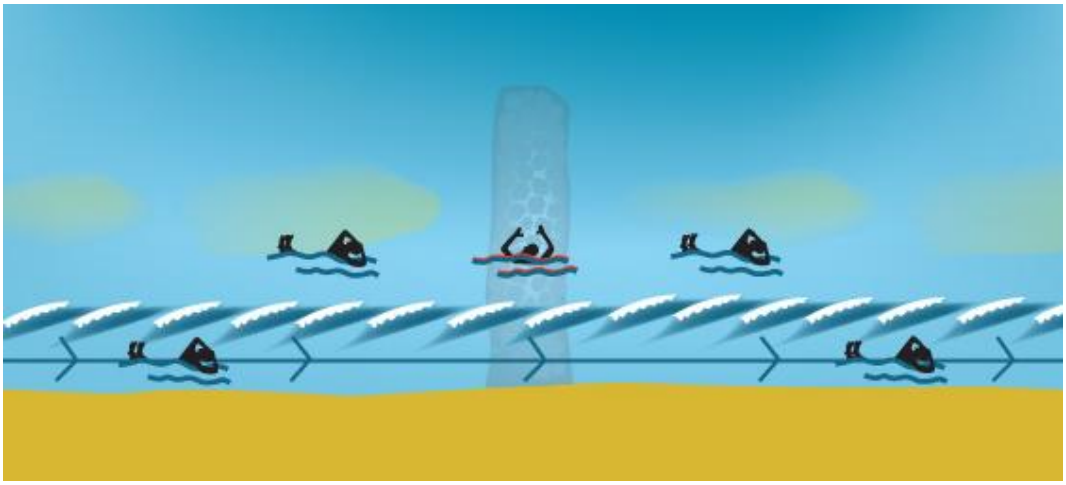


**Figure 3.3:** High tide and a strong longshore current. Swimmer either stay calm and float over the groynes or at lower water levels, get injured due to impact with the stones.

The lifeguards were asked to sketch a picture of conditions that will almost certainly cause hazardous currents, or 'a busy day' for them:

Sometimes when we wake up and look outside, we already know it's going to be a busy day. Nice weather, offshore wind and some waves in an otherwise calm sea, is one of those days. Other busy days are side shore wind (often SW but also NE), strength 4-5 Bft; around a few hours before high water the groynes cause troubles.

Another scenario is a few days of continuous strong side shore wind from the same direction. This causes a strong longshore current in the troughs. If groynes are present they cause injury during the HW period and many rips during LW.

The risk of bathers getting into trouble is greater in all scenarios with higher water temperatures and warm afternoons/evenings (often in August-September) and when many non-locals are on the beach.

Hazardous currents along the new beach configuration

The lifeguards on rip currents on the nourished beach, without groynes:

Instead of the almost certain location of the rip current near the groynes, the rip currents now tend to form at different places every time. This makes them **very unpredictable and hard for us to manage**. Some of the rip currents we encountered seemed to be not always directed straight offshore. This makes swimming out of the rip current trickier. Swimming out of the rip near a groyne meant swimming out of it slightly shore parallel, whereas now this technique could result in swimming straight up against the rip.

Their unpredictable nature sometimes caused that we spotted people in trouble later than before the nourishment, which **is certainly not beneficial for the rescue**. The unpredictability of the occurrence of these rips gives us a lot more work. We now have to keep an eye on individuals along the whole coastline instead of groups near certain groynes we were familiar with.

The lifeguards on other hazardous currents on the nourished beach, as illustrated by Figure 3.4-3.6

The area between the groynes used to be a relatively calm bathing area. We experience that the **disappearance of the groynes has caused a stronger longshore current close to the beach**. In one way this is not immediately negative, because the injury caused by the contact with the groynes is no longer an issue. But we feel that the longshore current picks up faster than before. In the old situation the wind needed to be strong and side shore for a couple of days to generate a current that we now experience within one day already. The **deep trough** between the first breaker bar and beach which is present after the nourishment, combined with this **strong longshore current causes many people to drift far alongshore**. And sometimes this also leads to panic reactions and thus troubles. Especially when the current also takes them slightly oblique in offshore direction. When the trough slowly runs obliquely from the beach towards deeper water, this is certainly a hazardous situation for bathers. Trying to get back to where they entered the water will tire them and possibly end up in a rescue.

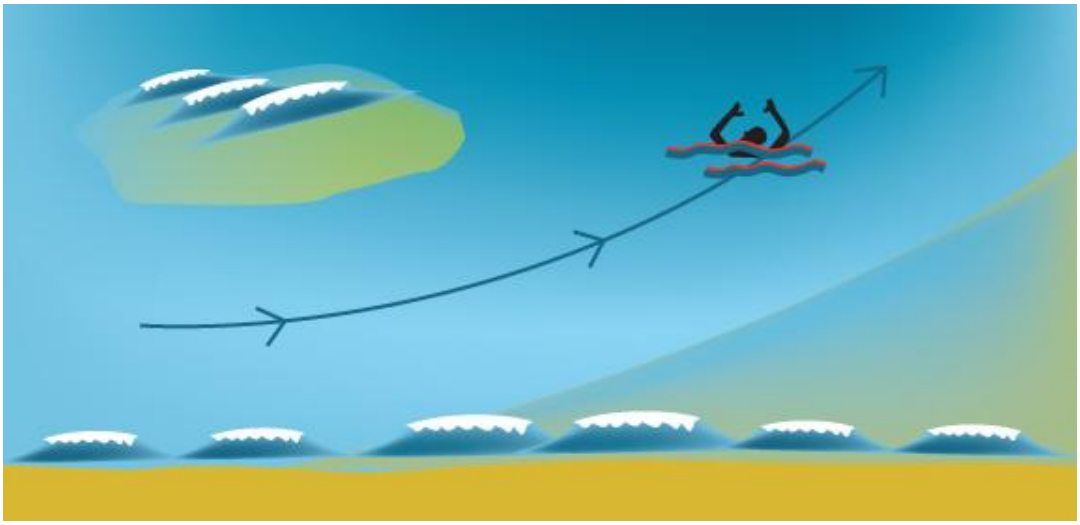


**Figure 3.4:** Strong longshore current through oblique trough is hazardous to swimmers.

Another place where we experience hazardous situations is near the lateral boundaries of the nourishment. It seems like the longshore current accelerates at these locations for some conditions, taking bathers by surprise. At Hoek van Holland several serious incidents took place near the northern boundary (connection with the original coastline) of the nourishment of 2004. A strong rip current formed here. Two persons drowned.

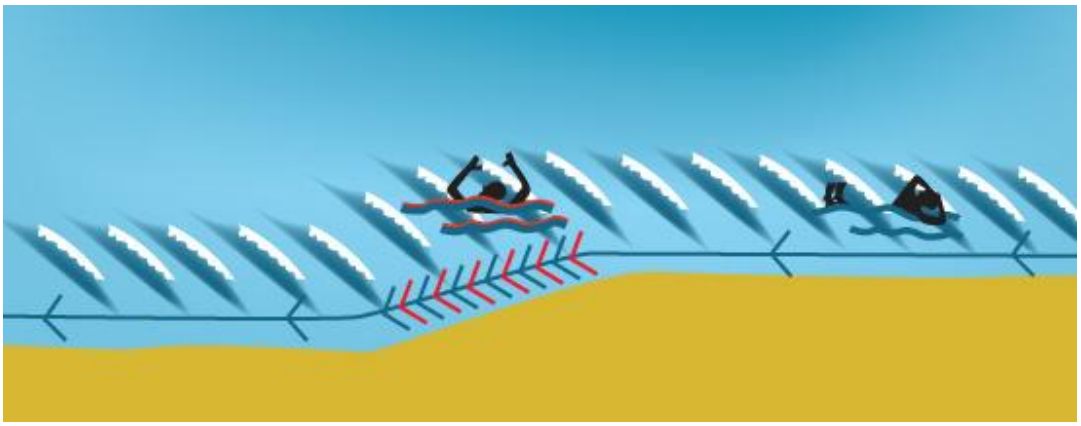


**Figure 3.5:** Acceleration of longshore wave driven current, surprising bathers, indicated as potentially dangerous.

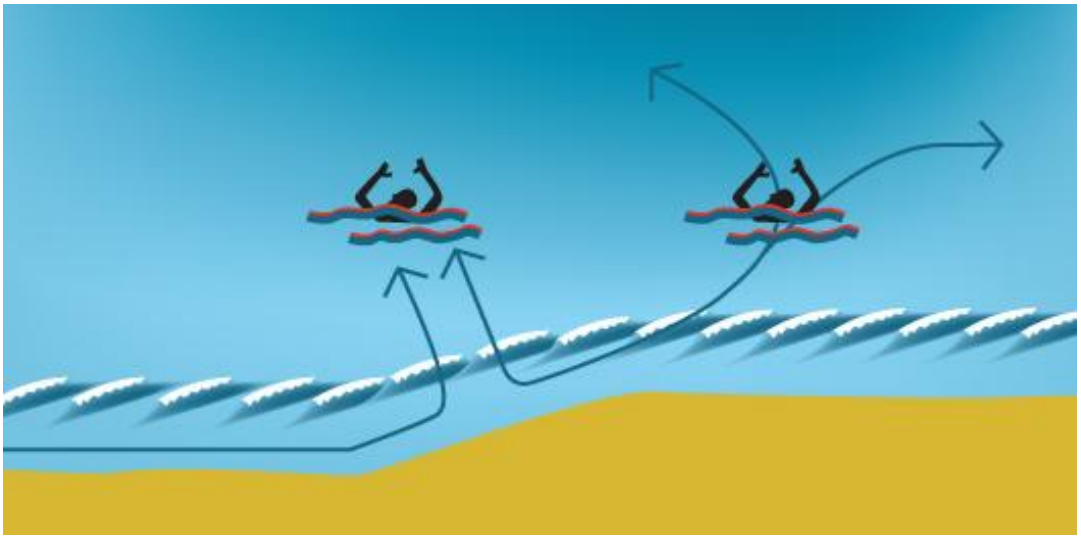


**Figure 3.6:** Due to near normal incident waves on gradient (lateral boundary of nourishment) rips have been observed by lifeguards.

Besides current related hazardous situations for bathers, the lifeguards reveal other hazardous aspects of the new beach configuration, illustrated by Figure 3.7 and 3.8:

After the nourishment a high water berm and a steep profile around the high water line formed, leading to an unusually deep trough. The **steep profile** caused a strong, short surf zone at high tide, to which bathers weren't used to. This **short, strong surf combined with the deeper trough behind it is especially dangerous to children.**

The berm and steep profile also **blocks our view** on the waterline, making it harder to keep an overview of the surf zone.

At some places a very **shallow breaker bar** (crest just under the low water line) developed between **50 and 100m from the low water line**. At low tide many people were drawn to the breaker bar. The rising tide filled the trough and at the same time caused a **longshore current in the trough making it hard for people to swim back** to the beach. The breaker bar also caused practical difficulties for us, because our boats couldn't get over the shallow bar around low tide, keeping us trapped in the trough.

Sometimes the shallow breaker bar was incised by rip channels. Bathers walking over the bar in alongshore direction would step into the rip channel, panic and try to swim to the beach or breaker bar, which could in some cases both be impossible.



**Figure 3.7:** Scarp, steep slope, short strong surf.

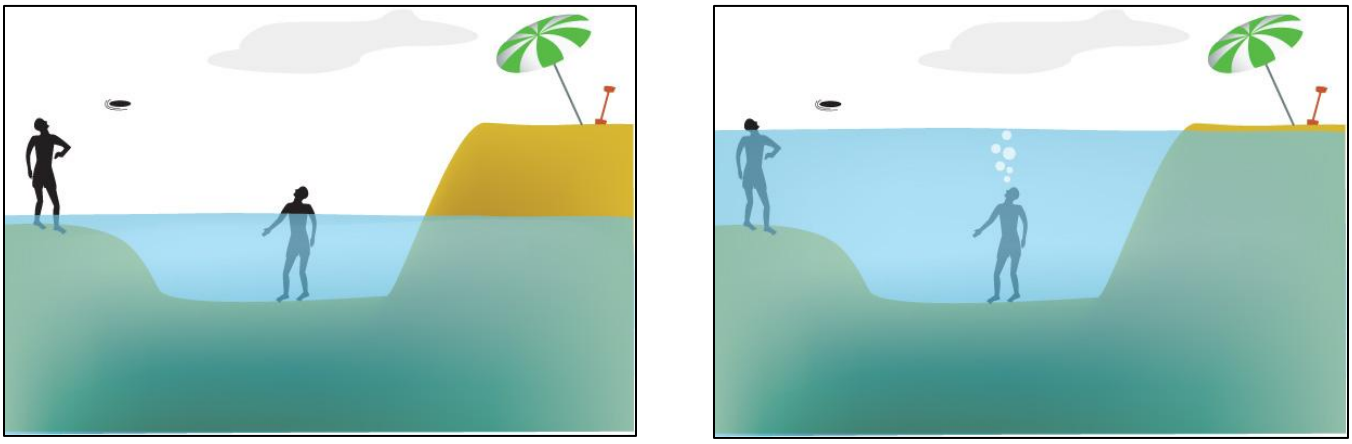


**Figure 3.8:** Shallow low tide bar, combined with deep trough, cut of bathers during rising tide. Low tide situation indicated in left figure. High tide situation indicated in right figure.

Another remark with respect to freshly nourished beaches is the formation and disappearance of sandbars and troughs in the intertidal area. The **bars and troughs seem to be very dynamic**. Moreover, the landward side of the bar would be very steep with loosely packed sand. This makes patrolling or launching boats trickier.

The morphology in between the groynes used to be more stable and predictable.

Two photos are shown to indicate the steep beach profile and berm on the nourished beach (Photo 3.5 and Photo 3.6).

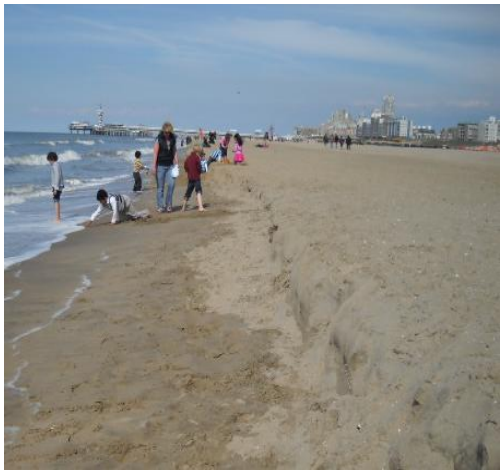


**Photo 3.5:** HW Berm

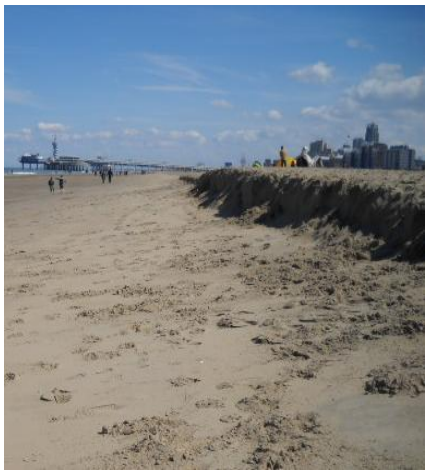


**Photo 3.6:** Steep profile around the HW line.

Summing-up the observations of the interviews and monitoring of beach season 2010 one can conclude that:

- unfamiliarity with the local situation increases the risk of being surprised by hazardous currents as a swimmer
- panic is a detrimental factor, playing an important role in the course of a hazardous situation
- bather swim back to their reference point on the beach, regardless of the current direction. When they don't get closer, panic and exhaustion can have serious consequences
- rip currents near emerged **groynes** are thought to be almost permanently present
- strong longshore currents combined with emerged **groynes** are hazardous to swimmers because rips are present next to the **groynes**
- strong longshore currents combined with (barely) submerged **groynes** are hazardous to swimmers because of the risk on collision and resulting injury thereupon
- according to the lifeguards **the conditions** that could cause a busy day for them on the beach with **groynes** are:
    - side shore wind (4-5 Bft), two to three hours before high water, warm water and nice weather or
    - waves combined with offshore negligible wind
- the **unpredictable** occurrence of rip currents on the open **nourished** beach are of major concern of the lifeguards
- the **direction of the rip** currents on the open **nourished** beach varies, making it harder to get out of the rip, even for the lifeguards
- along the **nourished beach** strong longshore currents combined with deep troughs are hazardous to swimmers in the rising tide period, and when troughs run slightly oblique to the shoreline
- the lifeguards perceive a steep beach slope, deep troughs and shallow breaker bars of the nourished beach to have a negative effect on swimmer safety
- compared to the rather stable morphology in between the groynes of the old beach, the nearshore morphology on the nourished beach is very dynamic and thereby less predictable. This has a negative effect on swimmer safety

### 3.4 Rescue reports: analysis approach

Besides the monitoring of the beach season of 2010 in Scheveningen and the interviews with the lifeguards, rescue reports are analysed. The rescue reports of the HVRB and GVRB were used to:

1. assess critical conditions and locations on groyned and nourished beaches.
2. investigate whether a causal relation exists between swimmer safety and certain wave, weather and tidal conditions.

A dense description of which information is filed in the reports and how the reports are analysed will be given next. Results of the analysis are presented in section 3.5.

Rescue reports include rescues of bathers, but also sprained ankles or equipment failure related rescues of kite surfers and small sailing vessels. Because this research aims at swimmer safety in relation to nearshore currents, rather than sprained ankles on the beach, the reports have been filtered on incidents with bathers in the nearshore related to hazardous currents.

The period for which information is available is limited to the presence of the lifeguards on the beach. This is roughly from the 15th of May to the 15th of September. In this period they are present in weekends and school holidays from 10am to 7pm.

The available rescue reports of the HVRB and GVRB and the number of relevant rescues are listed in Table 3.1. Distinction is made between unnourished (groynes present), nourished (no groynes present) or partly nourished beaches (stretches with and without groynes along the city coastline).

**Table 3.1**: Years of available rescue reports, beach configuration and number of rescues of bathers

| Year | 's Gravenzande (rescues) | The Hague (rescues) |
|---|---|---|
| 2004 | Unnourished/ groynes (9) | - |
| 2005 | Unnourished/ groynes (2) | - |
| 2006 | - | - |
| 2007 | Unnourished/ groynes (4) | - |
| 2008 | Nourished/ no groynes (1) | - |
| 2009 | Nourished/ groynes reappearing (3) | Unnourished/ groynes (34) |
| 2010 | - | Partly nourished (12) |

Rescue reports of the GVRB are of the years 2004-2005 and 2007-2009. Of the HVRB only reports of 2009 and 2010 are available.

Although the reports aren't always filed or complete, they provide a source of information of when, where and how the lifeguards need to come into action and generally include:

- Time of incident
- Type of incident
- Approximate location of incident
- Approximate wind direction and speed
- Time of HW and LW
- Direction of tidal current at times of the incident (only some cases) based on tidal phase

The information on hydrodynamic and meteorological conditions (called hydro meteo conditions from hereon) is based on their personal observation and estimates. Tidal levels and phase are read from tide charts. In the course of this research it became apparent that the observations regarding meteo conditions sometimes deviated from measurements at nearby (<10 km for Vlugtenburg and <20 km for Scheveningen) observation stations of the KNMI and Department of Water services of the Ministry of Public Works in Hoek van Holland. Therefore the measured conditions at nearby observation stations (Figure 3.9) at times of the rescues are used for this research. Moreover, to obtain a more comprehensive picture of the hydro meteo conditions at times of the rescues, additional parameters have been selected for analysis, which are all readily available through the KNMI and Ministry of Public Works databases. An overview of the total ensemble of parameters is given in Table 3.2.




**Figure 3.9**: Measurement locations of waves, weather and tide.

For most parameters hourly measurements at Hoek van Holland are used, except for the water level in Scheveningen, which is measured in the harbour of Scheveningen. The magnitude of the tidal current velocity at Scheveningen and Vlugtenburg is approximated by solving the momentum equation without advection term:

$$\frac{du}{dt} + g\frac{d\zeta}{dy} + cf\frac{|u|u}{h} = 0$$

In which $d\zeta/dy$ is the water level gradient in a certain tidal phase obtained through interpolation of the measured water level in IJmuiden (46 km North of Scheveningen) and Hoek van Holland (17 km South of Scheveningen). The total distance between the two measurement stations is 63 km. Interpolation gives the solution for the water level gradient half way between IJmuiden and Hoek van Holland. Scheveningen and Vlugtenburg are 14.5 km and 27.5 km to the south. Because the tidal wave is progressive with a phase speed of approximately 15 m/s, this gradient equals that in Scheveningen and Vlugtenburg with a temporal shift $\Delta t$ of about 16 and 30 minutes respectively (Ruessink et al., 2006).

$$\frac{d\zeta}{dy}(t-\Delta t) = \frac{\zeta_{ijm}(t) - \zeta_{sch}(t)}{63000}$$

The direction follows from the sign of the tidal current velocity and is schematised to be positive in alongshore northeast direction and negative in alongshore southwest direction.

**Table 3.2**: Rescue research parameters, source and remarks (HVH=Hoek van Holland, IJM = IJmuiden, SCH = Scheveningen)

| Parameter | Source | Remarks |
|---|---|---|
| Date & Time | RB | - |
| Location | RB | - |
| Water level | RWS | Measured values per 10 minutes at HVH and SCH |
| Tidal current velocity | RWS | SCH: Interpolation water level gradient at HVH and IJM<br>HVH: Interpolation water level gradient at HVH and IJM |
| Tidal current direction | RWS | SCH: Interpolation water level gradient at HVH and IJM<br>HVH: Interpolation water level gradient at HVH and IJM |
| Wind direction | KNMI | Hourly values of average last 10 min measurements at HVH |
| Wind speed | KNMI | Hourly averaged values at HVH |
| Wave height | RWS | Hourly averaged values at Europlatform |
| Wave direction | RWS | Hourly averaged values at Europlatform |
| Wave period | RWS | Hourly averaged values at Europlatform |
| Temperature (max + average) | KNMI | Maximum from hourly averaged values at HVH<br>Average from 9AM – 10PM hourly averaged values at HVH |
| Cloud cover | KNMI | Average from 9AM – 10PM hourly observations at Rotterdam |
| Day of the week | - | - |
| Precipitation | KNMI | Average from 9AM – 10PM hourly observations at Rotterdam |

The total ensemble of rescue reports (dataset) and the analysis of the rescue reports will be described in the next section.

### 3.5 Rescue reports: analysis results

This section presents the assessment of critical locations and conditions through analysis of the rescue reports. Furthermore the results of the research into whether a causal relation can be established between swimmer safety and specific hydro meteo conditions, based on the rescue reports filed by the lifeguards are presented. But first the dataset is introduced.

#### *3.5.1 The dataset*

The dataset of rescues performed by the GVRB and HVRB has been analysed on rescue location, type of rescue and conditions at times of the rescues, to see which rescues take place on which location and under which hydro meteo conditions on groyned and nourished (groyneless) beaches.

Table 3.1 reveals that more rescues have been performed in The Hague than in Vlugtenburg. The GVRB often acts preventive by closing sections of the beach for bathing when they think it isn't responsible to swim there. Unfortunately it isn't logged when and where they do this, so this information wasn't available for this research. The Hague doesn't close of parts of the beach, because they say it's often simply too crowded to enforce such a measure.

A remarkable observation is the number of rescues performed by the HVRB in 2009 (34) in relation to the total number of rescues (65) in the complete dataset spanning a time period of 7 years. Moreover, 17 of the 34 rescues of summer 2009 in The Hague were performed on one day: Saturday the 15th of August. This causes a major bias in the dataset. Nevertheless, this is the available data and will be used for this research. But, for the interpretation of the analysis results, it is good to have a clear image of this Saturday in August and the conditions on this day, since it has a great impact on overall results. Therefore, the locations and conditions at times of the rescues on this day are listed in Table 3.3.

**Table 3.3:** Conditions at times of rescues on Saturday the 15th of August 2009

| Rescue | Time MEZT | Location | h (cm NAP) | Tidal current velocity (m/s) | $H_s$ (m) | $\Theta_{waves}$ (° N) | $U_{wind}$ (m/s) | $\Theta_{wind}$ (° N) | T (°C) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12:30 | Z29 | 0.30 | 0.15 | 1.16 | 226 | 7 | 230 | 22.1 |
| 2 | 13:30 | Z45 | 0.01 | -0.02 | 1.25 | 226 | 7 | 240 | 22.1 |
| 3 | 13:40 | G47 | -0.04 | -0.06 | 1.34 | 227 | 7 | 240 | 22.1 |
| 4 | 14:20 | N43 | -0.21 | -0.20 | 1.23 | 227 | 7 | 240 | 22.7 |
| 5 | 14:30 | G46 | -0.24 | -0.23 | 1.27 | 227 | 7 | 240 | 22.7 |
| 6 | 14:30 | Z40 | -0.24 | -0.23 | 1.27 | 227 | 7 | 240 | 22.7 |
| 7 | 14:40 | Z23 | -0.27 | -0.26 | 1.25 | 227 | 7 | 240 | 22.7 |
| 8 | 15:40 | Z24 | -0.42 | -0.37 | 1.26 | 227 | 6 | 240 | 22.8 |
| 9 | 15:40 | Z45 | -0.42 | -0.37 | 1.26 | 227 | 6 | 240 | 22.8 |
| 10 | 16:10 | N43 | -0.49 | -0.38 | 1.35 | 228 | 5 | 220 | 24.1 |
| 11 | 16:50 | Z24 | -0.51 | -0.35 | 1.38 | 228 | 5 | 220 | 24.1 |
| 12 | 17:00 | Z22 | -0.48 | -0.33 | 1.37 | 229 | 5 | 230 | 25.2 |
| 13 | 17:30 | Z45 | -0.57 | -0.28 | 1.51 | 230 | 5 | 230 | 25.2 |
| 14 | 17:40 | G43 | -0.53 | -0.26 | 1.47 | 230 | 5 | 230 | 25.2 |
| 15 | 17:50 | Z29 | -0.60 | -0.24 | 1.49 | 232 | 5 | 230 | 25.2 |
| 16 | 19:00 | Z43 | -0.41 | -0.07 | 1.36 | 232 | 9 | 240 | 22.3 |
| 17 | 19:10 | Z4- | -0.37 | -0.04 | 1.39 | 232 | 9 | 240 | 22.3 |

Table 3.3 shows Saturday the 15th of August was a warm day with a moderate, side shore wind (SW, 4 Bft) and waves of approximately 1.3 m also from the SW. All rescues were groyne related. The number of the location indicates which groyne. Prefix Z, N or G indicates south side, north side or tip of the groyne respectively. Groyne numbers below 40 indicate groynes on the south side of the harbour. Groynes numbers above 40 are groynes north of the harbour.

Figure 3.10 shows the water level (solid blue line) and approximated tidal current (dashed cyan line) for Saturday the 15th of August. The rescues are depicted by the red crosses. It shows most rescues have been performed during the low tide period, when the crests of the groynes (approximately at 0 m NAP) are emerged from the water. The red vertical lines in Figure 3.3 indicate slack waters. The approximated tidal current was directed southwards between 13.30 AM and 19.30 PM (in between red lines). And directed northward between 19.30 PM and sunset.

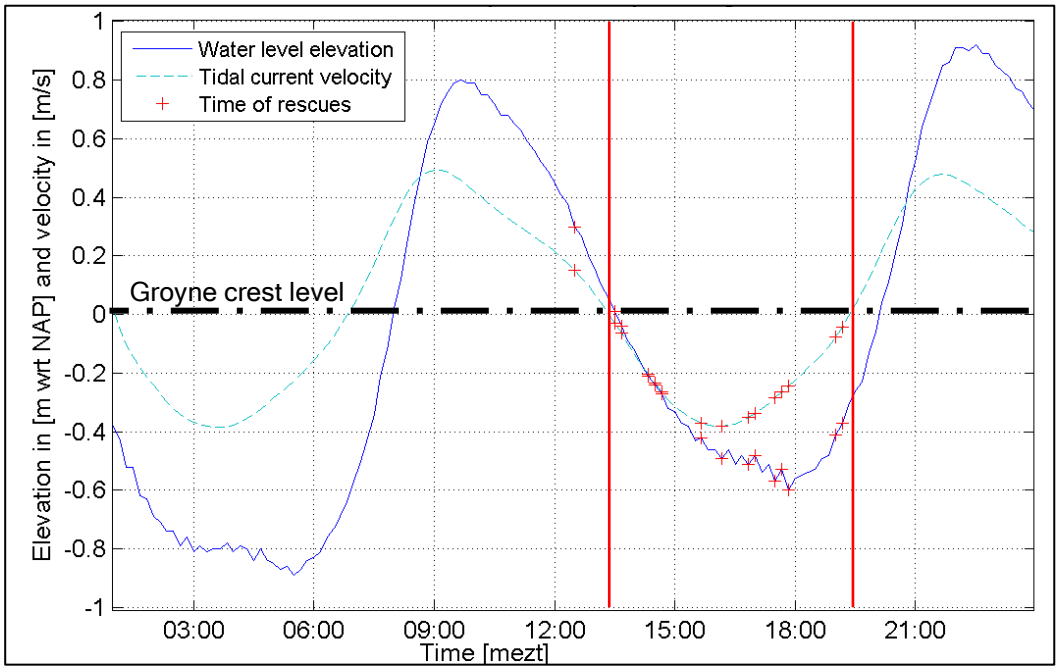



**Figure 3.10:** Water level elevation (blue line), approximate tidal current magnitude and direction (dotted cyan line) and rescues (red crosses) on Saturday the 15th of August 2009.

In the next sections all rescues in the dataset will be analysed, starting with the locations of the rescues.

*3.5.2 Locations*

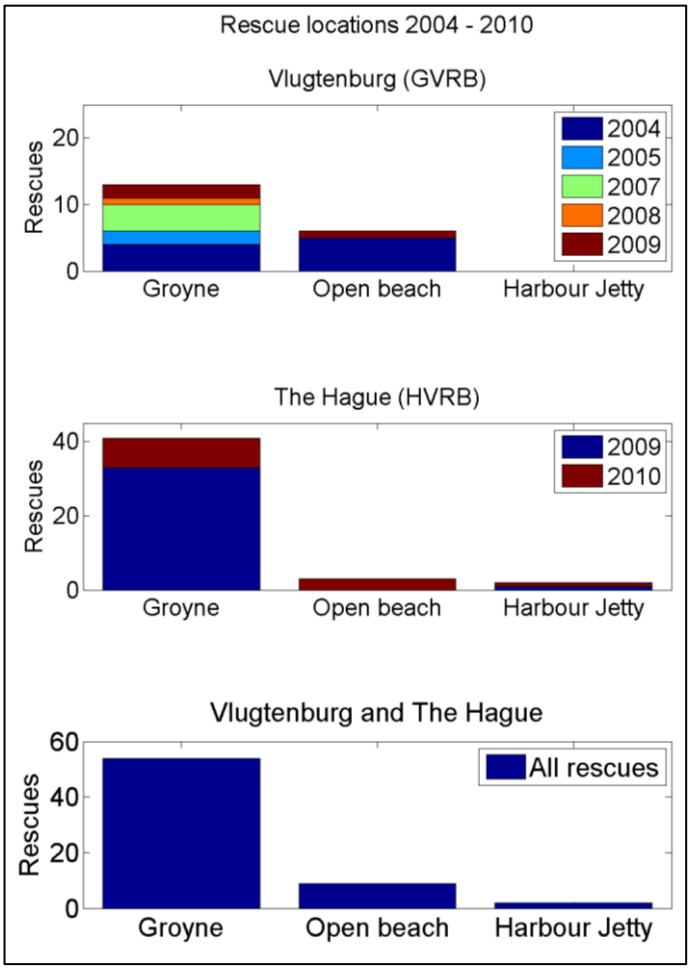
Looking at all the 65 rescues in the data set, most rescues have been performed near groynes (Figure 3.11). Moreover, the rescue reports suggest only rip current related rescues have been performed.

The rescues in 2004 that weren't groyne related have been performed at the northern lateral boundary of a large beach and shore face nourishment at Hoek van Holland in 2004. According to the lifeguards of the GVRB strong rip currents formed near the connection of this nourishment with the original coastline at Vlugtenburg, causing serious problems for swimmers and even two drownings.

In 2008 the large dune compensation and beach nourishment was executed at Vlugtenburg covering the groynes with sand (see section 3.2). No groyne related rescues were performed at Vlugtenburg in that year. The GVRB rescues near groynes in 2008 and 2009 as indicated in the top panel of Figure 3.11, took place at Ter Heijde, where groynes were still present and the GVRB assisted the rescue brigade of Ter Heijde. The first rescues on the open beach of Vlugtenburg were performed in 2009.

At The Hague all rescues have been performed near groynes and the northern harbour jetty in 2009. In 2010, when the coastline of The Hague was partly nourished (see section 3.2) still most rescues were performed near groynes (9) as opposed to the nourished open beach without groynes (3).

The survey amongst the lifeguards revealed that a strong longshore current can also be hazardous. An explanation for the absence of longshore related rescues in the reports, is found (and confirmed by the HVRB) in the way the rescue reports are filed. The lifeguards file the number of the groyne where the rescue has been performed and what kind of rescue it was; in these cases near groynes, always rips. However, it could well be that the longshore current initiated the hazardous situation for the bathers by transporting them towards the groynes, but that isn't filed in the reports.




**Figuur 3.11:** Locations of rescues categorized in groyne, open beach and harbour jetty for years 2004 - 2010 for Vlugtenburg site (top), Scheveningen site (middle) and combined (bottom).

*3.5.3 Conditions*

Wind, waves, tide and temperature are the main parameters for the investigation of which conditions (can) lead to hazardous situations for bathers. But also day of the week, cloud cover and precipitation have been taken into account. The distribution of the rescues over these parameters is plotted, to find out whether some conditions favour rescues and thus hazardous currents for swimmers.

<u>Wind</u>

Looking at the wind conditions at times of the rescue reveals a slight tendency towards side shore wind and onshore wind with a large alongshore component leading to more rescues.

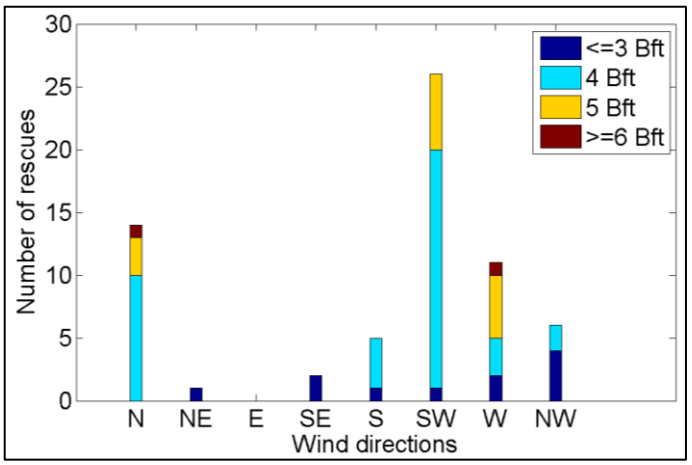



**Figure 3.12:** Rescues distributed over wind direction and -strength at times of the rescues. Colours indicate wind strength in Bft scale.

The beaches involved are facing NW. So wind from the S, SW, W and N have an alongshore component. Figure 3.5 shows the local wind direction and wind strength at times of the rescues. The large SW bin contains the rescues of Saturday the 15$^{th}$ of August, so biases the results. But still, wind with an alongshore component seems to favour hazardous conditions. Figure 3.12 reveals that straight alongshore winds (SW and NE) of moderate strength (3-5 Bft)

and slightly more oblique side shore winds (W and N) of greater strength (4-6 Bft) caused most rescues. Weak (side) offshore winds (SE to S) and straight onshore wind (NW) seem to have caused fewer rescues. Figure 3.12 reveals easterly winds seem to be less troublesome for bathers.

Tide

Lifeguards indicated that when the crest of the groynes are emerged from the water, during the low water (LW) period, hazardous currents can form near the groynes. Therefore, the rescues have been plotted over wind direction, together with the tidal current direction and indication of low- and high water period. A positive tidal current velocity greater than 0.10 m/s is categorized as *flood tidal current* (northward) and a negative tidal current velocity smaller than -0.10 m/s as *ebb tidal current* (southward). Absolute tidal current velocities smaller than 0.10 m/s are indicate as near zero (u~0 m/s).

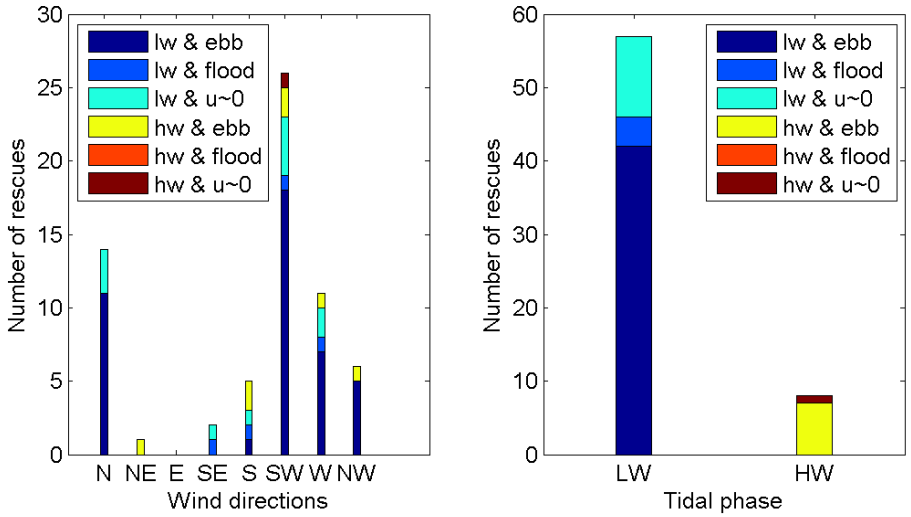



**Figure 3.13 Left:** Rescues distributed over wind direction at times of the rescue. The colours of the bars indicate water level and approximate tidal current direction. **Right:** Low tide or high tide period at times of rescues.

Figure 3.13 convincingly reveals that most rescues have been performed during the low water period. In most of those cases the tidal current was directed southward (ebb current) or near zero, but for some cases the tidal current had already changed direction and gained strength (u > 0.10 m/s). During the high water period only rescues were performed combined with a near zero current velocity or the ebb tidal current. So falling, low tide and the first period of rising tide cause most rescues. It could be a coincidence, but the left panel of Figure 3.13 reveals that the rescues performed at times of northerly wind the tidal current was also directed to the south. For bins SE and S this is not the case. For most rescues with SW to NW wind direction, the tidal current direction seems to be directed southward.

Waves

Along the Dutch coast waves from the SW to W are often related to the local wind. Waves from the NW to N can also be generated further away, and consequently not be related to the local wind conditions. The wave conditions (direction and height) have been plotted together with the rescues divided over the wind directions. Figure 3.14 clearly shows that local SW and W wind mostly coincide with waves from the SW and W. These are also the most energetic conditions at times of the performed rescues.

For the rescues performed during waves from the NW, approximately 30% coincide with NW wind. The other part thus causes rescues combined with different local wind conditions. This is an indication of swell waves from the NW causing rescues, rather than locally generated wind waves from the NW.

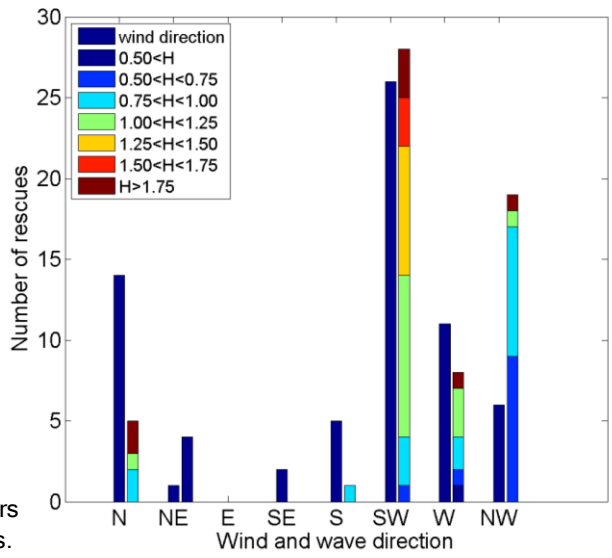



**Figure 3.14**: Wind- and wave direction. Colours indicate wave height per wave direction in meters.

Temperature, weekdays, rain and cloud cover

Besides waves, wind and the tide that determine the nearshore currents, the amount of people on the beach could also influence swimmer safety. Therefore the rescues have been analysed on temperature, days or weekends. Mostly because warm weather and a day off work encourages more people to go the beach. For all rescues the temperature (T) at times of the rescue is plotted in Figure 3.15. Daily maximum ($T_{max}$) and daily averaged temperature ($T_{mean}$) between 9AM and 10PM are shown as well.

Figure 3.15 reveals most rescues have been performed at temperatures between 19 and 25°C and sporadically on really hot days (>25°C).

To see whether rescues vary over weekdays or weekend all days on which a rescue has been performed are plotted in the left panel of Figure 3.16. Apart from the spike on Saturday (bear in mind Saturday 15th of August 2009) no real indications of specifically troublesome days of the week can be detected, other than slightly less rescues have been performed on Monday. Remarkably, some rescues have been performed at temperatures of 15-17°C. The lifeguards already told that some people just have to go into the water, because their on holiday near the beach: these could be some of those cases. When plotting the times of rescues a peak is revealed around the afternoon hours (Figure 3.16, right panel). This could be an indication of a peak in beach visitors since this is often the warmest moment of the day.

Rain and cloud cover have also been investigated. The results are plotted in figure 3.17 and remarkably reveal that daily averaged values of cloud cover for rescues are more or less evenly distributed. But cloud cover at times of the rescue itself seems to be either minimal or very thick. Unsurprisingly, all rescues have been performed without precipitation.

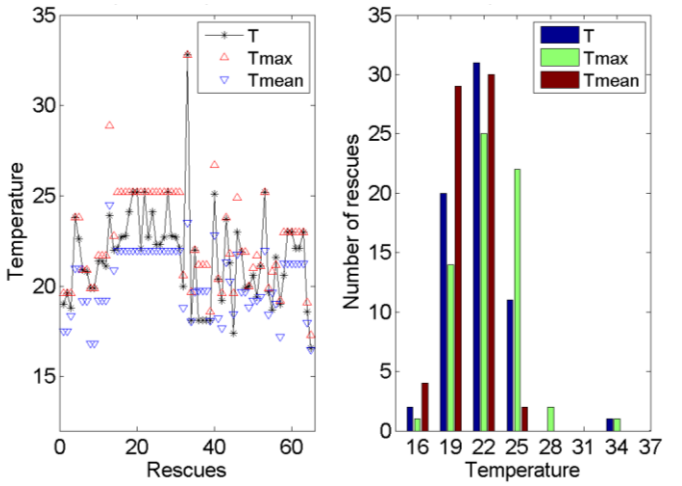
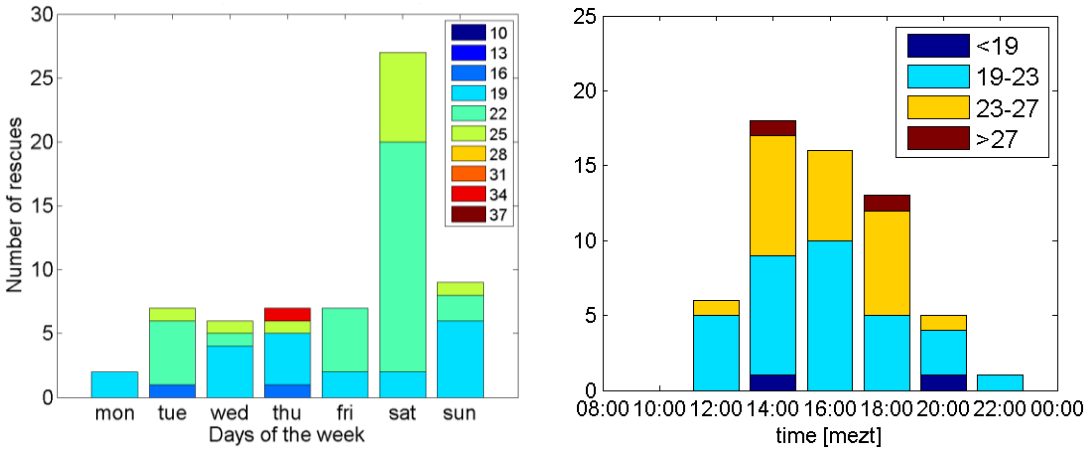



**Figure 3.15 Left:** Temperature at times of rescue (T), maximum ($T_{max}$) and mean temperature ($T_{mean}$) of the day of rescue. **Right:** Distribution of rescues over temperature.

**Figure 3.16 Left:** Rescues distributed over the days of the week. Colours indicate temperature in °C. **Right:** Rescues distributed over the hours of the day. Colours indicate temperature in °C.



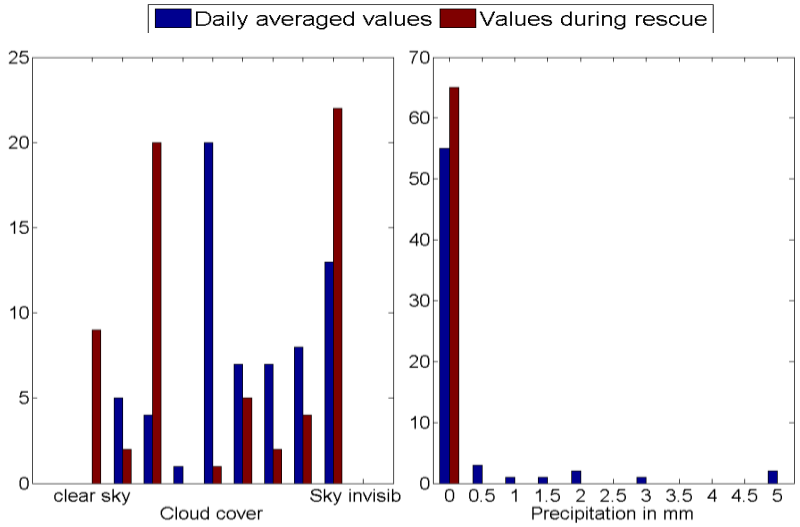




**Figure 3.17:** Cloud cover **(left)** and precipitation **(right)** at times of the rescues and daily averaged values on the day of the rescues.

The observations of the lifeguards indicated that side shore wind, low tide and groynes are a bad combination for swimmer safety because rips are formed near the groynes. Until this far, the data of the rescue reports points in the same direction. The analysis of the other parameters doesn't reveal a specific relation of these parameters with the rescues. In the next section wind and wave conditions are analysed for rescues on the groyned and groyneless (nourished) beach.

*3.5.4 Open nourished beach versus groyned beach*

To reveal whether the conditions that caused rescues on the nourished beach are different from those that caused rescues near groynes the rescues on both type of beaches have been analysed separately. Figure 3.18 shows narrow and wide bars with different colours. The narrow bars in both panels correspond to the wind direction at times of the rescues. The legend (applying to both panels) indicates wind strength in relation to the colours of the narrow bars. The wide bars represent the wave direction at Europlatform. The colours indicate mean wave period in seconds, and correspond to the legend in the left panel. The panels itself show the rescues on the nourished beach (left panel) and the groyned beach (right panel). For example, a rescue on the groyned beach with waves from the SW and a mean wave period of 4 s would fall in the right panel, in the blue part of the wide SW bin. If the wind for that rescue would be SW Bft 5, it would fall in the right panel, in the purple part of the narrow SW bin.

From Figure 3.18, which is based on all rescues, it is clear that during the rescues on the nourished beach nearly shore normal incident waves (NW and W) prevailed over obliquely incident waves (SW and N). The wave periods are almost all greater than 5 s (purple and pink colours), indicating longer waves (Dutch standards) and thus stronger refraction toward the beach.
For the groyne related rescues this is vice versa. Shore parallel orientated conditions cause the greater part of the rescues and wave periods are mostly smaller than 4.5 s (blue colours) for the groyne related rescues. Moreover, from the NW bars in the left panel, one can derive that the wave conditions (T >4.5 s) that caused rip currents on the nourished beach were not related to the local wind direction and strength (3 Bft). This could indicate that swell waves (longer period waves, not related to the local wind direction) are related to the occurrence of rip currents on the nourished beach. Whereas a significant amount of shorter crested oblique incident waves, related to the local wind direction (generally called: wind sea) have caused the majority of rescues on the groyned beaches (right panel)

Overall, the prevailing wind conditions are mild when rip currents on the nourished beach caused problems for swimmers, with an exception for W winds. On the groyned beach slighty more energetic side shore wind conditions caused problems for swimmers.

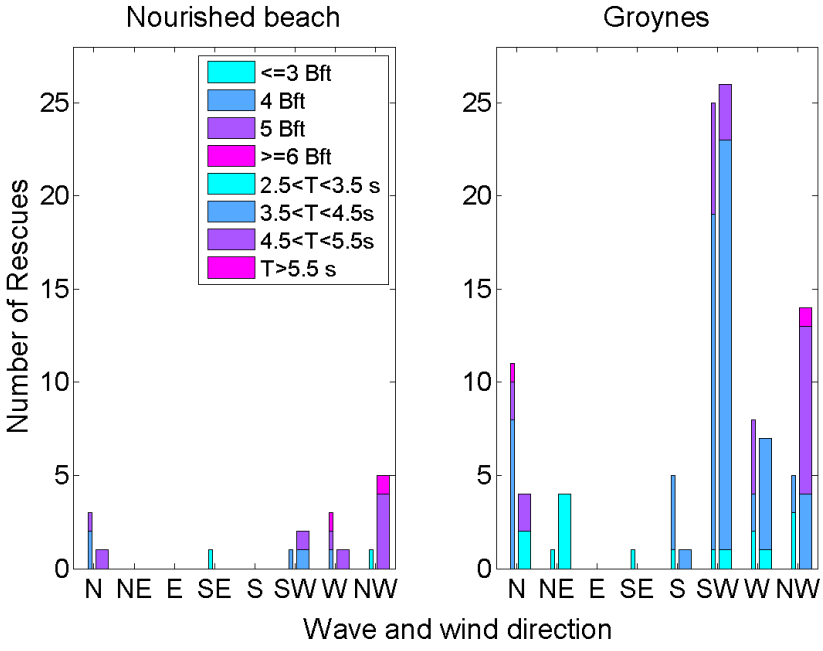



**Figure 3.18:** Wind and wave directions for rescues on the nourished beach **(left panel)** and near groynes **(right panel)**. The narrow bars in both panels correspond to the wind direction at times of the rescues. The colours of the narrow bars correspond to the wind strength as indicated in the legend. The wide bars in both panels correspond to the wave direction at Europlatform at times of the rescues. The colours of the wide bars correspond to the mean wave period as indicated in the legend.

For the beach season of 2010 in The Hague a similar analysis has been performed. This time, it involves rescues performed in the same summer season, along 11 km of coastline of The Hague and thus with the same kind of hydro meteo conditions on the different parts of the beaches along the coastline. The only difference is the beach configuration: nourished (without groynes) and unnourished (with groynes). No conclusion as to whether one configuration is safer than the other will be drawn, based on one year of data. The interest lies in the occurrence of hazardous currents and the conditions causing them. Like Figure 3.18, Figure 3.19 also shows longer period, nearly shore normal incident waves for the rescues on the nourished beach. Notice the lack of N and SW waves in the left panel

of Figure 3.19, as opposed to a significant contribution of shorter period waves from the N and SW for rescues on the groyned beach. The right panel of Figure 3.19 shows that near-normally incident waves (NW) also cause problem for swimmers on the groyned beach.

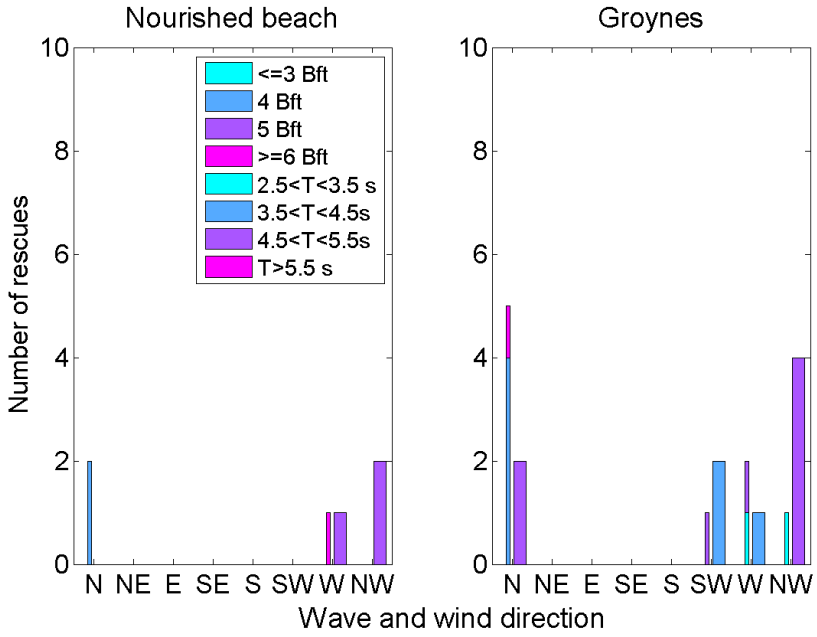



**Figure 3.19:** Wind and wave directions for rescues on the nourished beach **(left panel)** and near groynes **(right panel)** for beach season 2010 in The Hague only. The narrow bars in both panels correspond to the wind direction at times of the rescues. The colours of the narrow bars correspond to the wind strength as indicated in the legend. The wide bars in both panels correspond to the wave direction at Europlatform at times of the rescues. The colours of the wide bars correspond to the mean wave period as indicated in the legend.

So far the observations reveal that:

- most rescues are performed near groynes or other coastal structures
- the majority of rescues on the beaches with groynes were performed during side shore winds (SW and NE) of moderate strength (3-5 Bft) and oblique onshore winds of greater strength (4-6 Bft) with a large alongshore component (W and N)
- rip current related rescues on the open nourished beach were performed during (near) normally incident longer period waves and mild wind conditions. Waves from the NW only coincide with NW wind for 30% of the cases. The rest of the NW wave conditions coincides with rescues performed with offshore winds(SE and S) and mild wind from the N. This could indicate that swell type wave conditions (for Dutch standards) are responsible for the occurrence of rip currents on the open nourished beach
- in general most rescues are performed during the low water period
- wave conditions during rescues are most energetic for rescues performed with SW and W wind on the groyned beach.
- air temperature varies between 15 to 34 °C, though most temperatures at times of the rescue are between 19 to 25 °C
- the amount of rescues per day of the week is relatively evenly distributed, although a peak is visible on Saturday (70% Saturday 15$^{th}$ of August 2009) and a dip on Monday.

An interesting question is whether all occurrences of the conditions which prevailed at times of the rescues, have caused rescues. This would imply a causal relation between the conditions and swimmer safety. The next section will describe how this is investigated.

### *3.5.5 Causal relation rescue conditions and swimmer safety*

The observations until now suggest combinations of beach configuration, locations and hydro meteo conditions that cause hazardous situations for bathers. However, is that is true for all occurrences of these conditions? Are the conditions causing the rescues unique? To investigate this, distributions of the occurrences of the parameters mentioned in Table 3.2 have been made of observations between 9AM and 10PM during the beach season. This is the most likely period that bathers are actually at the beach and rescue data is available. Comparing the distribution of the conditions at times of the rescue with the seasonal occurrence of these conditions could reveal whether the rescue conditions are unique and thus give a high risk on hazardous currents for bathers or not.

Wind direction and wind speed

Both panels in Figure 3.20 show normalised distributions of the occurrence of wind conditions during the beach seasons of 2004 to 2010 (left bars) and of the wind conditions for which rescues have been performed (right bars) in these seasons. In the left panel only the wind direction is shown. In the right panel information on wind strength is added through colours, corresponding with values listed in the legend.

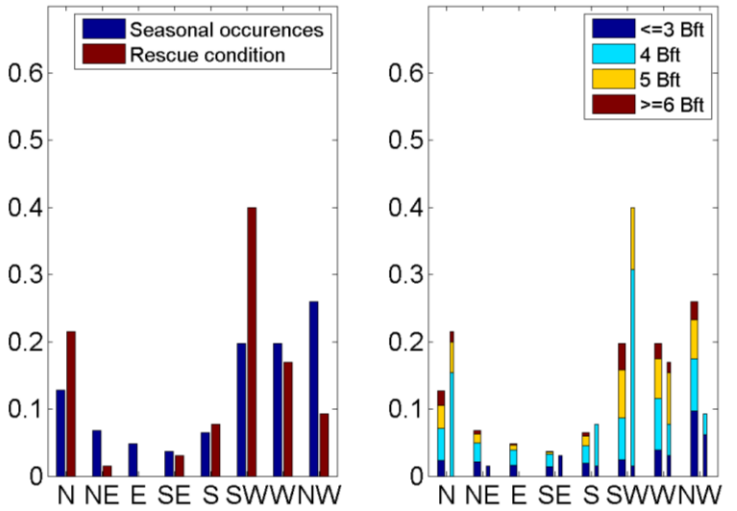



**Figure 3.20:** Normalised distributions of seasonal occurrence of wind conditions and at times of rescues. The left bars represent the seasonal occurrences and the right bars the occurences at times of the rescues. The left panel shows only directions. The right panel also shows wind strength in colours, which correspond to the values in the legend.

The two distributions (of the seasonal occurrence of wind conditions and rescues) look very much alike. This implies all wind directions cause relatively the same problems. Because N, SW and W winds occur more often, also more rescues have been reported for these conditions than for the other conditions. NW wind is an exception; it occurs more often than that it causes rescues (relatively speaking) . But besides the occurrence of these conditions, one could conclude that N and SW wind cause rescues sooner than the onshore (NW) wind conditions. Still there is no solid indication of specific conditions leading to hazardous situation for bathers. One could say there is no greater risk on rescues for a particular wind direction, other than that E and strong NW winds are slightly safer.

Temperature

The graph in Figure 3.21 shows the normalised distribution of the mean and maximum temperature during the summer months (red and yellow bars) and of the days the rescues were performed (blue bins). The two distributions look very much alike. Although days with a maximum temperature between 21°C and 26°C occur less often than days with a maximum temperature between 17°C and 21°C, they are associated with relatively more rescues. So one could say, a warm day has a higher risk on rescues than average summer temperatures.

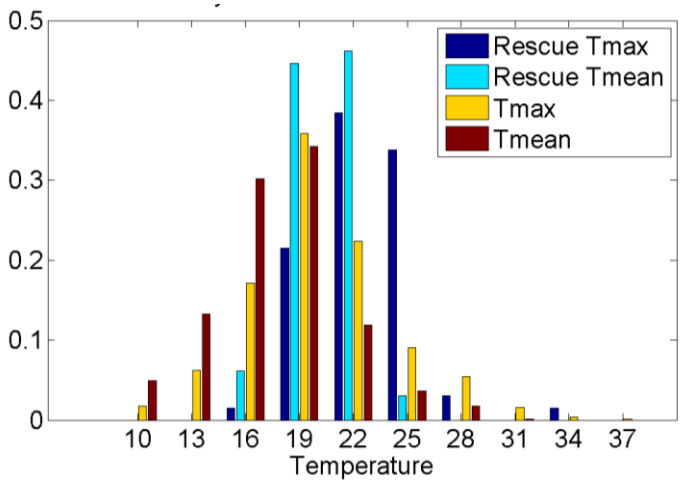



**Figure 3.21:** Normalised distributions of the temperature on rescue days (max = dark blue, daily mean = light blue) and seasonal occurrence daily temperatures (max = yellow and red = daily mean).

Cloud cover

Very few rescues were performed during many clear skies in summer. It seems that moderately clouded days favour rescues (Figure 3.22). The graph in the right panel of Figure 3.22 presents the daily-averaged precipitation of rescue days (blue) and seasonal distribution of daily-averaged precipitation (red). The two distributions overlap mostly. It shows dry days occur very often in Holland (contrary to the complaining of the Dutch, that it always rains a lot). Other than that, it shows that even on days with precipitation (occurring relatively rarely in the summer seasons) rescues are performed.

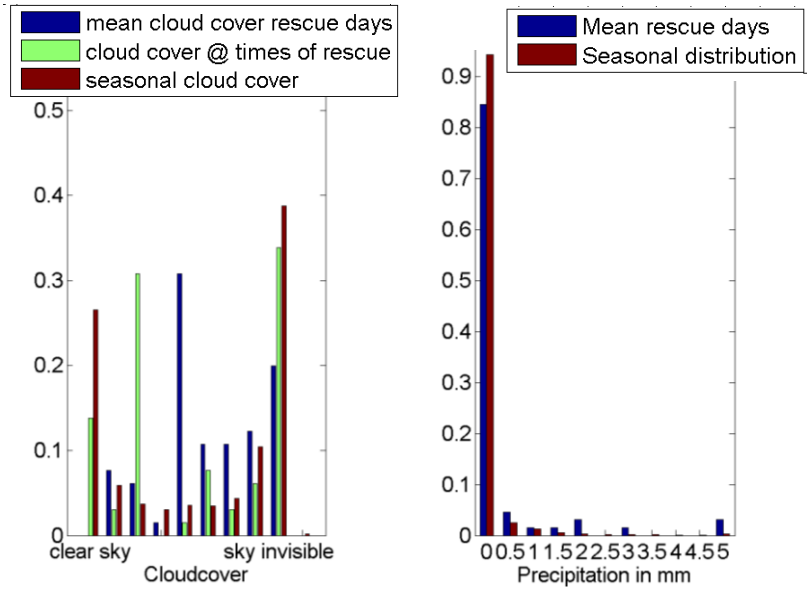



**Figure 3.22 Left:** Normalised distributions of cloud cover at times of rescues (green bars), daily averaged cloud cover on rescue days (dark blue) and seasonal occurrence of cloud cover (red). **Right:** Normalised distribution of daily precipitation on rescue days (blue) and seasonal occurrence (red).

The results of the investigation into a causal relation between hydro meteo conditions indicate that the distributions of the conditions at times of the rescues mostly coincide with or have the same shape as the distribution of the seasonal occurrence of the conditions. In other words, the conditions at times of the rescues are not a unique set. Moreover, the analysed conditions cause relatively the same amount of rescues. The only difference is that some conditions occur more often than the other. With respect to the wind conditions one could say there is no greater risk on rescues for a particular wind direction, other than that E and strong NW winds are slightly safer. And although higher temperatures (>22°C) occur less often than colder days, most rescues have been performed on the warmer days. Which is an indication that the amount of beach visitors is an important factor in swimmer safety. But, no distinct causal relation between swimmer safety and specific hydro meteo conditions can be established, based on the performed analysis and available data.

### 3.6 Overall conclusions swimmer safety

Based on the performed research the following conclusions can be drawn regarding nearshore currents and beach configurations in relation to swimmer safety:

*General swimmer safety aspects:*

- unfamiliarity of bathers with the local situation and sea increases the risk of being surprised by hazardous currents
- panic often plays a detrimental factor during the course of a rescue
- bathers swim back towards their point of reference on the beach, regardless of the current direction

*Positive effects of groynes on swimmer safety:*

- morphology in between the groynes is more or less the same throughout the season. This gives bather and lifeguard a certain familiarity with the local situation.
- groynes decelerate the current towards the waterline. When they are emerged a calm, relatively flat bathing area ensures safe bathing in between the groynes, when the longshore current is weak.
- The formation of rip currents near groynes is found to be predictable according to the lifeguards. Experienced lifeguards ‘know’ at which groyne hazardous situations can occur. However, still bathers needed to be rescued near groynes.

*Negative effect of groynes on swimmer safety:*

- when the groynes are emerged, any longshore current is deflected along the side of the groynes. Strong offshore directed currents are invoked. In combination with deep channels, which are often present along the groynes, the immediate surroundings of the groynes are hazardous for swimmers.
- stones of the groynes cause injury to bathers when caught in a rip and trying to get on to the groyne or when they are being dragged over by strong longshore currents at higher water levels.
- most rescues are performed near emerged groynes or other coastal structures

- rip currents near emerged groynes are thought to be almost permanently present based on the variety of conditions that caused rescues near groynes

*Impact of the nourishment on swimmer safety:*

- rip currents are less predictable in occurrence, location and orientation.
- the unpredictability of rip currents on the nourished beach is of major concern of the lifeguards
- lifeguards experience a stronger longshore current close to the beach and in the trough between the first breaker bar and beach
- a steep beach slope, deep trough and shallow breaker bar have formed since the nourishment
- the new beach configuration can be dangerous for swimmers. Bathers are attracted to the shallow bar during low tide. In the rising tide period, the trough fills quickly, often combined with a rather strong longshore current. Bathers who could wade to the bar during low tide, are now forced to swim through the trough. The tidal flood current or any wave driven current, will transport swimmers longshore. When rip channels or obliquely offshore orientated troughs are present, the situation becomes very hazardous.
- the shallow breaker bars limit the striking force of the rescue brigades: their boats can get stuck on the bar, keeping them trapped in the trough.
- strong gradients in bottom topography have a negative effect on swimmer safety in general. Bathers are taken by surprise when they suddenly can't touch the bottom anymore. Any current can then cause trouble for bathers.
- the steep beach slope has caused short strong surf. Bathers can get knocked to the ground, causing injury. People can also have difficulties exiting the water through the strong short surf.
- berms and high water scarps block the view of the lifeguards on the surf and are thus perceived as negative with respect to swimmer safety.

*Critical conditions and locations*

- most rescues are performed near groynes or other coastal structures
- the majority of rescues on the beaches with groynes were performed during side shore winds (SW and NE) of moderate strength (3-5 Bft) and oblique onshore winds of greater strength (4-6 Bft) with a large alongshore component (W and N)
- rip current related rescues on the open nourished beach were performed during (near) normally incident longer period waves and mild wind conditions. Waves from the NW only coincide with NW wind for 30% of the cases. The rest of the NW wave conditions coincides with rescues performed with offshore winds(SE and S) and mild wind from the N. This could indicate that swell type wave conditions (for Dutch standards) are responsible for the occurrence of rip currents on the open nourished beach
- in general most rescues are performed during the low water period
- wave conditions during rescues are most energetic for rescues performed with SW and W wind on the groyned beach.
- air temperature varies between 15 to 34 °C, though most temperatures at times of the rescue are between 19 to 25 °C
- the amount of rescues per day of the week is relatively evenly distributed, although a peak is visible on Saturday (70% Saturday 15$^{th}$ August 2009) and a dip on Monday.

*Causal relation conditions and swimmer safety*

No distinct causal relation between swimmer safety and hydro meteo conditions could be established, based on the performed analysis and available data. However, there are some combinations of hydro meteo conditions and locations that have caused more rescues than others. This is mainly due to the fact that some conditions prevail more often than others, resulting in a higher rescue count for these conditions. But partly also due to the combination of these conditions with the beach configuration and the associated presence of rip currents caused by these conditions. Side shore orientated conditions and low tide caused many rescues in rips near groynes. For the same conditions no (rip current related) rescues where performed on the open nourished beach. Conditions that did cause rescues on the open beach, where strongly onshore orientated: longer period near-normally incident waves and mild (offshore) wind conditions. These conditions also caused rescues on the beaches with groynes. But, as for all conditions that caused rescues, not all occurrences of these conditions caused rescues. This leaves a causal relation between hydro meteo conditions and swimmer safety hard to establish.

The belief of the lifeguards that moderate to fairly strong (4-5 Bft) side shore wind, low tide and nice weather can cause a 'busy day' for them, is confirmed. However, not every day that fits this description has caused rescues, which also leaves a causal relation between specific hydro meteo conditions and swimmer safety hard to establish.

# 4 Current and bathymetry measurements at Scheveningen

## 4.1 Introduction

This chapter presents the results of a measurement campaign performed at Scheveningen beach before and after it was artificially nourished in the beginning of 2010. Nearshore current velocities have been measured with GPS drifters. Measurements took place at specific locations for wave-, weather and tidal conditions which, according to lifeguard rescue reports, led to many rescues in the past. GPS drifters record the position with high accuracy enabling to calculate the velocities and to make a coupling of drifter trajectories with the bottom contours. Bottom topography is surveyed just before or after the current measurements using PWC (jetski) surveys around high tide and low wave energy conditions. The sub aqueous surveys are complemented with RTK GPS 4wd- and walking surveys on the sub aerial beach around low tide, giving a full coverage from -5 m to +3 m above MSL.

Commonly posed questions with respect to nearshore currents and swimmer safety are:

- When and where are rip currents likely to form?
- When is the current pattern predominantly longshore orientated and strong?
- In which part of the nearshore and under which forcing can (strong) longshore currents be expected?
- In which part of the nearshore and under which forcing can (strong) cross shore currents be expected?

Chapter 3 concluded that no causal relation between specific hydro meteo conditions and swimmer safety could be established. However, the survey amongst the lifeguards and the analysis of the rescue reports revealed that:

- strong side shore orientated conditions favoured the occurrence of hazardous currents for bathers near groynes (rips) and a strong alongshore current in the troughs of the nourished beach
- the occurrence and locations of rip currents on the nourished open beach were unpredictable but hypothesize to be more likely to form in swell type wave conditions (for Dutch standards), in the absence of strong side shore orientated conditions.

This implies that the occurrence of rip currents along the open beach of the South Holland coast is strongly related to - and limited by - the longshore current. The measurements are used to investigate whether this can be confirmed. And moreover, whether a more generic balance between longshore orientated (no rips) and cross shore orientated current pattern (rips) along the open beach can be established based on specific hydro meteo conditions.

In an attempt to answer these questions the following approach is followed:

1. Measure and identify hazardous currents and locations for bathers on a groyned and nourished beach.
   Based on Chapter 3, features of interest in the nearshore current pattern are:
   - Concentrated offshore directed currents (rips)
   - Strong alongshore directed currents
   - Strong gradients in shoreline orientation (rips/acceleration of current)

2. Quantify characteristics of these hazardous currents and locations
   Occurrence, location, (offshore) extent, current velocity and driving processes are determined.

3. Investigate the regime for the occurrence of rip currents along the open nourished beach and near groynes. And investigate which parts of the cross shore exhibit which current velocities.
   The cross shore distribution of the longshore and cross shore current velocity of the measurements are used to investigate whether certain locations in the cross shore are correlated to strong velocities. The relative magnitude of the longshore and cross shore drifter velocities in the measurements is analysed and related to the occurrence of rip currents.

The measurements, data processing and results of the analysis will be described hereafter. But first the field site will be introduced.

## 4.2 Field site

Scheveningen is located on the south west coast of the Netherlands, about 17 km north of the Port of Rotterdam entrance channel and Hoek van Holland (Figure 4.1). This part of the Dutch coast is a long open sandy coast with groynes from Hoek van Holland to a few kilometres north of Scheveningen and suffers structural erosion. To mitigate the erosion the entire coastline from Hoek van Holland to the North of the Hague Scheveningen beach has been subjected to several beach and shore face nourishments over the last decades gradually covering the groynes with sand.

Scheveningen beach can be classified as a meso tidal beach with neap and spring tidal range in the order of 1.2 and 2.2 m respectively. Mean wave height $H_{m0}$ is 1.2 m, mean wave period $T_{m0}$ is 5 s and the waves are predominantly approaching shore obliquely from the southwest and north-northwest directions (Wijnberg et al, 2009, in De Schipper et al, 2011).




**Figuur 4.1:** Scheveningen. Dashed red line indicates nourished area in winter 2009-2010. source: google earth

Before the beach season of 2010 a part of the beach of Scheveningen has been artificially nourished (Figure 4.1, dashed red line) moving the coastline approximately 100 m seaward. The beach configuration pre and post nourishment is shown in Photo 4.1 and Photo 4.2. The numbers 42 – 45 in Photo 4.1 are the numbers of the groynes. Groyne 45, just south of the Pier, is the northern boundary of the nourishment. The northern side of groyne 45 was still present after the nourishment, the southern side was covered with sand.

### 4.3 Instruments

Nearshore current velocities have been measured with GPS drifters. GPS drifters record the position with high accuracy enabling to calculate the velocities and to make a coupling of drifter trajectories with the bottom contours. Bottom topography is surveyed just before or after the current measurements using PWC (jetski) surveys around high tide and low wave energy conditions. The sub aqueous surveys are complemented with RTK GPS 4wd- and walking surveys on the sub aerial beach around low tide, giving a full coverage from -5 m to +3 m above MSL.

*4.3.1 TU Delft Nearshore Monitoring Jetski (Nemo)*

The bottom topography is surveyed just before or after the current measurements using PWC (jetski) surveys (Van Son et al, 2009) around high tide and low wave energy conditions for the sub aqueous part. The TU Delft Jetski Nemo is used to survey the bottom topography (Photo 4.1). The jetski surveys are complemented with RTK GPS 4wd- and walking surveys on the sub aerial beach around low tide. The longshore resolution of the survey tracks is 25 m.The water depth below the jetski is measured with a Hydrobox Single Beam Echo Sounder (SBES, sounding frequency 10Hz). The position of the jetski (in horizontal and vertical direction) is determined by the Septentrio GPS receiver. An accurate position is calculated by using the Real Time Kinematic (RTK-GPS) technique. The GPS position of the jetski is corrected through correction values obtained through a UMTS connection with a base station. SBES and GPS measurements are logged continuously on an on board laptop with Hypack




**Photo 4.1:** TU Delft NEarshore MOnitoring Jetski

Hydrographic software. A monitor mounted on the jetski provides real time information to the pilot, such as position, instrument status, sailed survey tracks and planned survey lines.

*4.3.2 GPS surf zone drifters*

Surf zone velocities are measured with GPS drifters (Photo 4.2). The GPS drifters are extensively described by MacMahan et al. (2009). They consists of a buoyant 0.1 m by 0.3 m PVC body on which a 0.7 m by 0.03 m PVC mast is attached. A GPS antenna on a 0.05 m metal disk is attached to the mast. Three fins along the shaft of the body are attached for sail area. The drifters are designed to minimise surfing back to the beach on the roller of a breaking wave. They tilt on wave impact. A flat plate attached to the bottom reduces surfing and ballast weights attached to the bottom increase stability of the drifters. The drifters were shown to closely follow simultaneous dye release and passive swimmers.



**Photo 4.2:** GPS data loggers attached to PVC buoys. (GPS drifters)

The GPS data loggers are housed in a waterproof box attached to the mast. The loggers internally record carrier phase information on one frequency at a sampling frequency of 0.5Hz. The capacity of the loggers allows for measurements up to three hours. Position accuracy is in the order of 10 m. But the logger data can be post processed with GPS correction values of a nearby base station. Post processed horizontal position accuracy is in the order of 50cm and less. Vertical post processed position accuracy is in the order of meters. This is acceptable because the interest lies in accurate horizontal positions.
Biggest advantages of the GPS drifters are their deployment flexibility, low production costs and small weight. Large areas can be covered with relatively little effort. They offer the possibility to visually identify interesting flow patterns during the measurements, such as rips or longshore accelerations. And also to zoom in to such features in greater detail, right away. Moreover, if one regards swimmers as more or less floating objects, subjected to the flow in the upper part of the water column, the drifters can be regarded as passive representatives.

### 4.4 Bottom topography

The bottom topography before the nourishment of 2010 (28 January 2009, Figure 4.2 left) was characterized by subtle subtidal bars with a crest at -2.5 m NAP approximately 20 m seaward of the tip of the groynes. NAP is the Dutch Ordnance Datum, close to mean sea level. In between the groynes flat bars and shoals were present, with crests at -1.5 to -1 m NAP. Variation in bottom elevation is small except for the area adjacent to the groynes. Deep channels with a depth of -3 to -4 m NAP were present. The depth of the scour holes at the tip of the groynes was around -4 m NAP. The crest of the groynes are at MSL. Mean slope of the beach face around the waterline (-1.5 to +2 m NAP) was around 1:50 directly north of the harbour to 1:35 from groyne 43 northward.

The beach nourishment of spring 2010 created a gradient in the coastline (17 February 2010, Figure 4.2 right). North of the gradient the bars have disappeared and the mean slope of the beach face from -4 to +2 m NAP is around 1:18. The mean slope of the beach face from -5 to -2 m NAP south of the gradient hasn't changed. But from -2 to -1 m NAP a steep slope of 1:15 is created by the nourishment. From -1 to +2 m NAP the mean slope is around 1:30. The bars along the southern part of the beach have disappeared as well.

Figure 4.3 shows the bottom topography for the 10$^{th}$ of April (left) and 14$^{th}$ of July 2010 (right). It reveals a rapid change in the coastline gradients and beach profile in the first month post nourishment. Gradients in the contours between -2 and +2 m NAP are milder and the beach profile is less steep. Several shore connected bars developed directly north of the harbour with crests at -1 m NAP. The bars




**Photo 4.3:** Beach of Scheveningen pré-nourishment 2009. Groynes 42-45 visible.



**Photo 4.4:** Nourished beach of Scheveningen 2010.Groynes 42-44 covered by the nourishment, 45 still present.

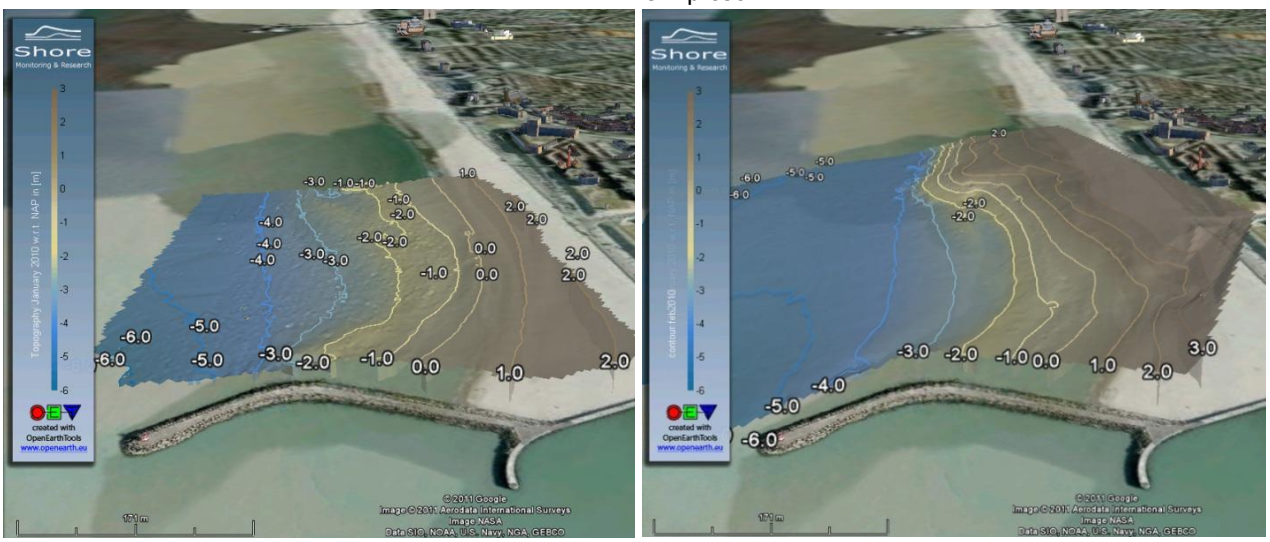



**Figure 4.2:** Bottom topography at Scheveningen beach before (left) and directly after the nourishment of 2010. Colours indicate elevation in m with respect to NAP.

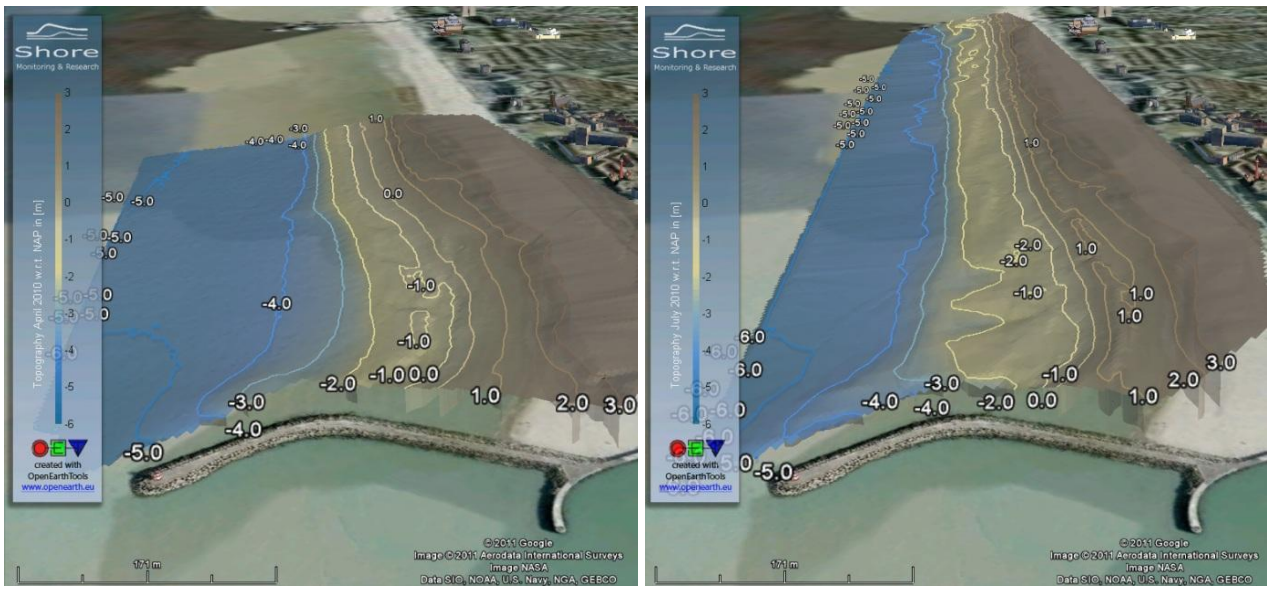



**Figure 4.3:** Bottom topography at Scheveningen beach 10th of April 2010 (left) and 14th of July 2010 (right). Colours Indicate elevation in m with respect to NAP.

gradually migrated seaward getting separated from the beach by a shore parallel trough. The trough deepens in southward direction from -1.5 to -3 m NAP where it connects to an equally deep rip channel along the harbour jetty.

The last survey performed in July (Figure 4.3 right) shows an almost straight coastline (around MSL). Just north of the rip channel along the harbour jetty sand has accumulated almost until the tip of the jetty. Distinct breaker bars are visible north of the jetty, with crests around -1 m NAP. Triangular shaped depressions are visible on the outer edge of the bars. There is still a trough between the bars and the dry beach which feeds the rip channel along the jetty. Further north the beach is characterized by several slightly oblique sub tidal bars with crests at -1.5 to -1 m NAP connected to the intertidal area at the northern end of the bar. Several oblique troughs and channels (depth of -2 m NAP) cut through the bars and connect to deeper water (-3 to -4 m NAP) on the southern end of the bars, approximately 50 m from the low water line at most. In the intertidal area regular subtle bar trough patterns are visible with alongshore spacing of 150-200 m. The crest level of the bars in the intertidal area is around 0.50 t0 0.75 m NAP. The channels and trough levels are at approximately 0 and 0.25 m NAP.

### 4.5 Drifter deployment and post processing

Ten surf zone drifters were deployed during selected wave, wind and tide conditions (Table 4.1). The drifters were deployed throughout the surf zone in clusters or arrays (longshore/cross shore) depending on the experiment. When drifters exited the area of interest, washed onto on coastal structures or beached, they were retrieved and deployed again. A log sheet is kept to list time of deployment and retrieval of each drifter during the experiments. This ensures the selection of drifter data for analysis of only those parts where drifters were floating without any human interference. After GPS post processing and conversion to the Dutch RD NAP coordinate system of all drifter data, the log sheet was used to select the trajectories for analysis. Local time derivatives of x and y were used to determine the velocity along the drifter trajectory. The velocity signal per drifter track was filtered first to remove outliers. Outlier criteria were:

- a deviation from the mean velocity of the drifter track > $1.5\sigma_{\text{drifter track}}$
- velocities greater than 2 m/s.

Secondly, gaps in the time series of x and y were interpolated after which a running-mean averaging over 10 s was performed, using a zero-phase filter. Local time derivatives of the filtered x and y data were used to determine the velocity along the filtered drifter trajectories. Figure 4.4 shows the velocities based on the raw, despiked and filtered signal.

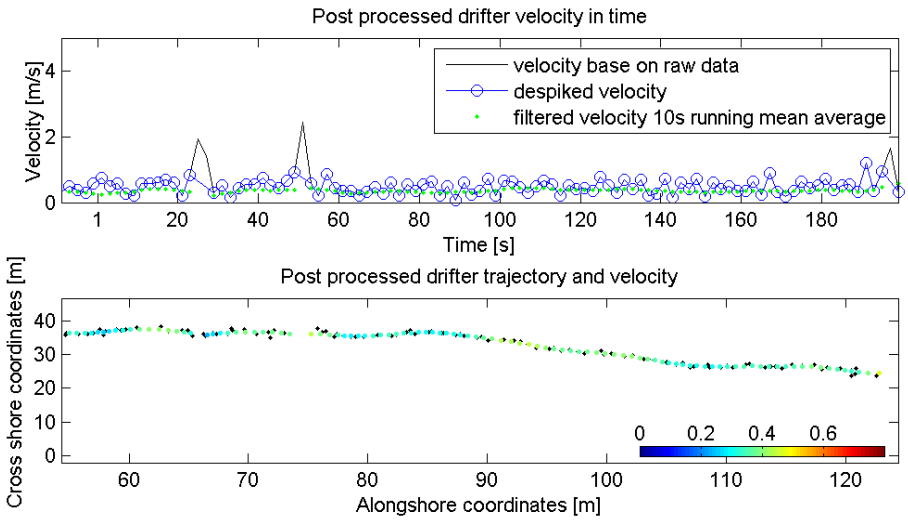



**Figure 4.4 Top:** Drifter velocity based on raw data (black), despiked velocity (blue) and filtered velocity using zero phase 10s running mean average. **Bottom:** Despiked x, y drifter positions (black), filtered x, y drifter positions using zero phase 10s running mean average. Colours indicate velocity along trajectory in m/s.

### 4.6 Drifter experiments

Seven 3-hour drifter deployments were performed. All deployments took place during specific wave, wind and tidal conditions (Table 4.1) and locations for which many rescues were performed in the past (Chapter 3). Offshore wave observations as well as the approximated parameters at the surf zone edge are listed. The surf zone edge is approximated by assuming a breaker index of 0.8 for incipient depth induced wave breaking of 1/3 of the highest observed waves ($H_{m0,b}/h_b = \gamma = 0.8$). The term $H_{m0}$ is used because the significant wave height, as provided in the wave data records, was obtained from the energy density spectrum between 30 - 500 mHz. Wave height at breaking point $H_{m0,b}$ is obtained through transformation of the measured significant wave height at the offshore

observation stations Europlatform 3 ($h$ = 32 m) for south westerly conditions and K13 ($h$ = 30 m)[1] for northerly conditions, using the dispersion relation for progressive linear waves and Snell's Law for straight and parallel alongshore depth contours.

The first two deployments (January and February) were pre-nourishment at groyne 42. During the first experiment the offshore wave ($H_s$ = 1.0 m, $T$ = 4.3 s) and local wind ($U$ = 5 m/s) direction was NE. Waves from the NE arrive fairly long crested at Scheveningen beach because they've refracted over almost 90° from the area of generation. The local wind direction NE is side shore, 'blowing' the wave crests into a more regular shape.
Conditions were slightly more energetic during the second deployment (February 9th) with higher short crested waves ($H_s$ = 1.2 m, $T$ = 5.0 s) from the North and obliquely onshore wind (NNE, $U$ = 7 m/s).

The April 16th deployments were performed two months post nourishment. No groynes were present along the beach. The deployments took place on the same day; in the morning during low tide and in the afternoon around high tide. In the morning the waves ($H_s$ = 0.9 m, $T$ = 4.0 s) and wind ($U$ = 6.5 m/s) were coming from the N. The waves were short crested and irregular.
In the evening conditions were slightly more energetic with slightly higher wave height and period ($H_s$ = 0.95 m, $T$ = 4.2 s) and stronger wind ($U$ = 9 m/s) from the N.

The conditions of the April experiment are similar to the first to experiments. Though the waves were shorter crested and less regular. The wind direction was less side shore orientated (N instead of NE).

In July the tips of groynes 42 and 43 and groyne 45 entirely reappeared from the sand. The first deployment on July 13th was during nearly shore normal approaching, fairly long crested, regular (for Dutch standards) waves ($H_s$ = 0.9 m, $T$ = 5.1 s). The wind was offshore ($U$ = 0.5 m/s) and it was low tide. In the course of the deployment the wind turned side shore a gained in strength (NE, $U$ = 4.5 m/s).
In the afternoon, during the second deployment, the wind turned obliquely onshore (N, $U$ = 3.5 m/s) and the waves ($H_s$ = 0.9 m, $T$ = 4.9 s) were less regular than in the morning. The experiment was conducted during falling tide around high water slack (change of tidal current direction from North to South).

On the 16th of July the drifters were deployed in high energy wave conditions ($H_s$ = 1.7 m, $T$ = 5 s) and strong side shore wind (SW, $U$ = 10 m/s). During these conditions the waves approach the coast very obliquely and break along fairly regular long crests. SW waves approaching Scheveningen are generally still in the area of generation. Meaning that for SW waves the wind is still a source of energy for wave growth in the course of refraction towards the coast. To account for this deep water wave angle is altered in landward direction with 10°. The resulting surf zone edge (Figure 4.11-4.12) is in agreement with the drifter paths. The experiment was conducted from mid to low tide. Groynes 45 and 46 were emerged from the water.

[1] http://www.knmi.nl/samenw/hawa/pdf/Handboek_H19.pdf, pagina 22

**Table 4.1:** Overview of drifter experiments, conditions and current pattern observations.

| Date | $H_{m0_0}$ (m) / $H_{m0_b}$ (m) | $T_{m02_0}$ (s) | $Dir_{_0}$ (° wrt shore normal) / $Dir_{_b}$ (° wrt shore normal) | Estimated Breaker depth $h_b$ (m) | Vertical tide (m NAP) | Horizontal tide Ebb (NE→SW) Flood (SW→NE) | Wind speed (m/s) | Wind Dir | Observations |
|---|---|---|---|---|---|---|---|---|---|
| **26 jan** | 1.0 / 0.4 | 4.3 | 85 / 19 | 0.5 | Falling tide -0.2 → -0.5 | Ebb | 5 | NE→ N | - Rip current at groyne |
| **9 feb** | 1.2 / 1.15 | 5.0 | 45 / 20 | 1.45 | Falling tide -0.2 → -0.6 | Ebb | 7 | NNE | - Rip current at groyne |
| **16 apr AM** | 0.9 / 0.85 | 4.0 | 40 / 18.5 | 1.06 | Low tide -0.6 → -0.86 →-0.8 | Ebb | 6.5 | N | - Predominant alongshore current along open beach<br>- Incidental short obliquely offshore directed currents on open beach<br>- Rip current at harbour jetty |
| **16 apr PM** | 0.95 / 0.93 | 4.2 | 35 / 16 | 1.15 | High tide 0.8 → 1.2 → 0.4 | Flood | 9 | N | - Predominant alongshore current along the open beach<br>- No rip currents on open beach<br>- Rip current at harbour jetty |
| **13 jul AM** | 0.9 / 0.99 | 5.1 | 20 / 8 | 1.23 | Low tide -0.2 → -0.6 → -0.5 | Ebb | 0.5 → 4.5 | E → N | - Rip currents on the open beach at times of weak alongshore current<br>- Rip currents at groyne |
| **13 jul PM** | 0.9 / 1.08 | 4.9 | 40 / 16 | 1.13 | Falling tide 0.8 → -0.3 | Flood → HW-slack → Ebb | 3.5 | NNW → NE | - Predominant alongshore current along open beach<br>- No rip currents on open beach<br>- Rip current at groyne |
| **16 jul** | 1.7 / 0.84 | 5 | 80 / 23 | 1.06 | Falling tide 0.0 → -0.5 | Ebb | 10 → 7 | SW | - Strong alongshore current along open beach<br>- No rip currents on open beach<br>- Rip currents and lee side eddies at groynes |

## 4.7 Observations

*4.7.1 Current pattern*

The drifter paths for all seven deployments are plotted in Google Earth, and when available, over the measured bottom topography (Figure 4.5 - 4.12). The colours along the paths represent drifter velocity.
The outer edge of the surf zone is indicated by the dotted red line, approximating the offshore most region of wave breaking during the measurements. The velocities shown in Table 4.2 – 4.5 have been determined by averaging drifter velocities over the duration of the experiment in and outside the surf zone and in the rip current near the groyne. The tables also present the standard deviation of the velocities in the different areas. This is an indication of the variability in current velocity in that particular area. The current velocities listed in the tables seem lower than the tracks visible in the figures. The reason for this is that slow drifters remain longer within the area for which the average current velocity is determined. Hence there are more low velocity observations than high velocity observations per unit area, biasing the data towards lower average velocities. This might cause the reader to underestimate the velocities, therefore the maximum current velocity per area has been listed as well.

The first experiments (January and February 2010, Fig. 4.5) show clear permanent rips adjacent to groyne 42. The offshore extent of the rip current is limited to the tip of the groyne for the first experiment and for the second experiment O(20 m) beyond the tip of the groyne. The mean velocity in the rip current is roughly twice as high as the mean velocity of the alongshore wave driven current (Table 4.2). The tidal current close to the tip of the groyne seems to increase upon passing the groyne where it meets the rip current head. For the February experiment, when the rip is quite strong, no clear distinction was observed in tidal current and rip current velocity. The rip current seems to extend further beyond the tip of the groyne 'pushing' the tidal current further offshore. The maximum rip current velocity for both experiments is roughly three times as high as the average wave driven current.

Drifters that skirted the tip off the groyne remained within the surf zone. The others were transported shore parallel with the tidal current and didn't re-enter the surf zone. The bottom topography shown in figure 4.5, had been measured a year previous to the current measurements for another purpose. The northern side of the groyne 42 wasn't included. Moreover, during the course of the first two measurements, the construction of the nourishment had already started in the northern part of the beach. The new coastline is indicated by the grey/sand shaded patches north of the groyne. This explains the direction of the drifters north of the groyne, which seem to move onshore, but are actually following the new coastline. Photo material of the measurements near groyne 42 on January the 26th is shown below in Photo 4.5 and Photo 4.6.

**Table 4.2:** Maximum, mean and standard deviation of velocities in different areas along the beach.

| Velocity | 26th Jan<br>max - mean - std (m/s) | 9th Feb<br>max - mean - std (m/s) |
|---|---|---|
| wave driven current | **0.30** - 0.14 - 0.03 | **0.65** - 0.27 - 0.10 |
| rip current groyne | **0.46** - 0.30 - 0.08 | **0.70** - 0.47 - 0.11 |
| tidal current | **0.37** - 0.25 - 0.05 | - |



**Photo 4.5:** Deploying drifters near groyne 42 26th Jan 2010




**Photo 4.6:** Drifters deployed in in rip near groyne 42.

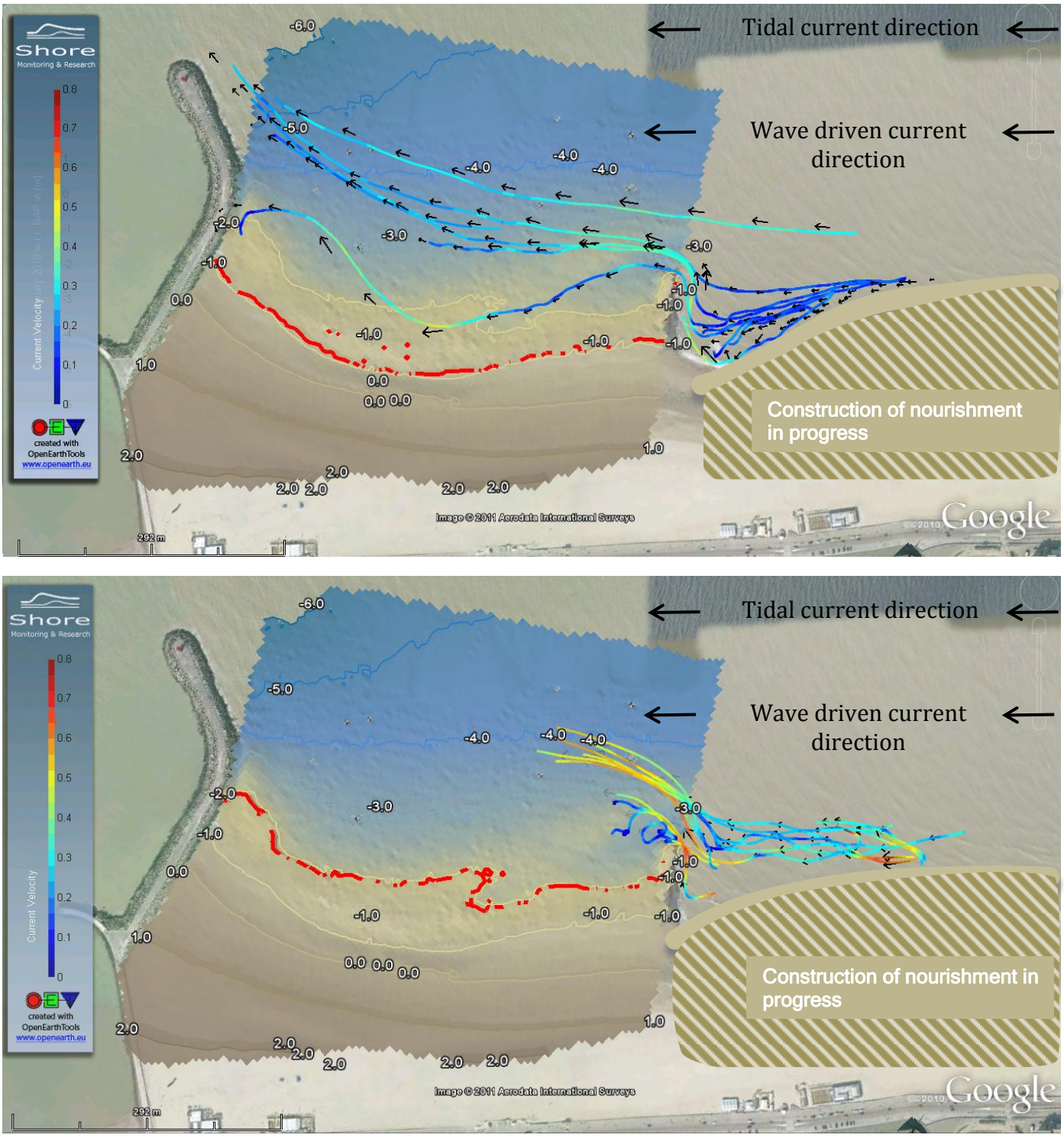



**Fig. 4.5:** Drifter trajectories Jan 26th 2010 (**top**) and February 9th 2010 (**bottom**). Colours indicate velocity along trajectory in m/s, red dotted line is surf zone edge indication. Blue/grey shading and contours indicate bottom elevation in m NAP. Beige shaded thick line indicates approximate waterline due to commenced construction of the nourishment.

The April experiments along the nourished beach (no groynes) indicate a clear alongshore orientated current pattern, without evident rip currents along the beach (Fig. 4.6 and 4.7). Bottom topography in the northern part wasn't measured. But can be assumed to be more or less similar to the most northern measured part show in Figure 4.6 and 4.7. Photo 4.7 and 4.8 provide an image of the coastline and conditions during the morning deployment.

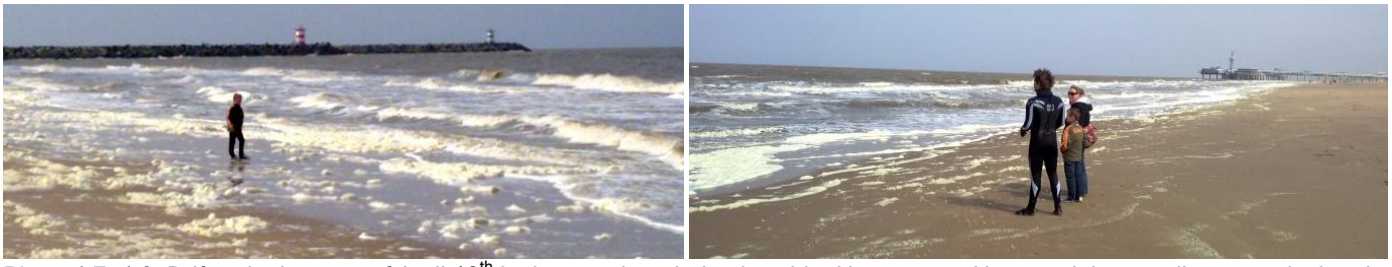


**Photo 4.7, 4.8:** Drifter deployment of April 16th in the morning, during low tide. No groynes. Near straight waterline towards the pier. Wave breaking on the first breakerbar in the northern part (Photo 4.7) and on the beach face (Photo 4.8)

In the morning deployment, during low tide, some obliquely offshore orientated flows have been measured in the surf zone at the northern part of the beach with velocity magnitudes in the order of 0.5 m/s (Figure 4.6 top, red arrows). The average alongshore wave driven current along the northern part of the beach is in the order of 0.35 m/s with quite a high standard deviation of 0.12 m/s and a maximum of 0.68 m/s. The mean tidal current velocity in the northern part is 0.25 m/s with a significantly smaller standard deviation of 0.04m/s. Along the gradient in the coastline a quite strong acceleration in the wave driven current was measured. Drifters acceleration inside the approximated surf zone is clearly visible in the bottom panel of Figure 4.6 The average current velocity along the gradient is 0.55 m/s with a standard deviation of 0.22 m/s and the maximum current velocity is in the order of 0.8 m/s.

The only evident rip current was measured along the harbour jetty. The average velocity in this rip was 0.19 m/s (standard deviation of 0.14 m/s), which is smaller than the average alongshore wave driven current along the rest of the beach. The maximum current velocity in the rip is 0.5 m/s, which is strong. Just north of the harbour jetty a trough feeds the rip current (Figure 4.6 bottom and Figure 4.7, black ellipse). The average current velocity (0.47 m/s) in this trough is quite high and varies in time as indicated by the rather large standard deviation (0.13 m/s, Table 4.3). The maximum current velocity in this trough is very high: 0.86 m/s.

Along the open beach all drifters were retained within the surf zone and eventually beached. Some skirted the outer edge of the surf zone, but eventually beached as well. The only drifters exiting the surf zone, were the ones caught in the rip current along the harbour jetty.

**Table 4.3:** Maximum, mean and standard deviation of velocities in different areas along the beach.

| Velocity | 16th April AM LW<br>max - mean - std (m/s) | 16th April PM HW<br>max - mean - std (m/s) |
|---|---|---|
| wave driven current northern part | **0.68** - 0.35 - 0.12 | - |
| tidal current | **0.44** - 0.26 - 0.04 | **0.62** - 0.32 - 0.18 |
| wave driven current gradient | **0.83** - 0.55 - 0.22 | **1.30** - 0.67 - 0.21 |
| wave driven current trough | **0.86** - 0.47 - 0.13 | **1.30** - 0.67 - 0.21 |
| rip current jetty | **0.51** - 0.19 - 0.14 | **0.59** - 0.29 -0.09 |




**Photo 4.9:** Executing drifter deployment April 16th in the afternoon, jetski on assist.

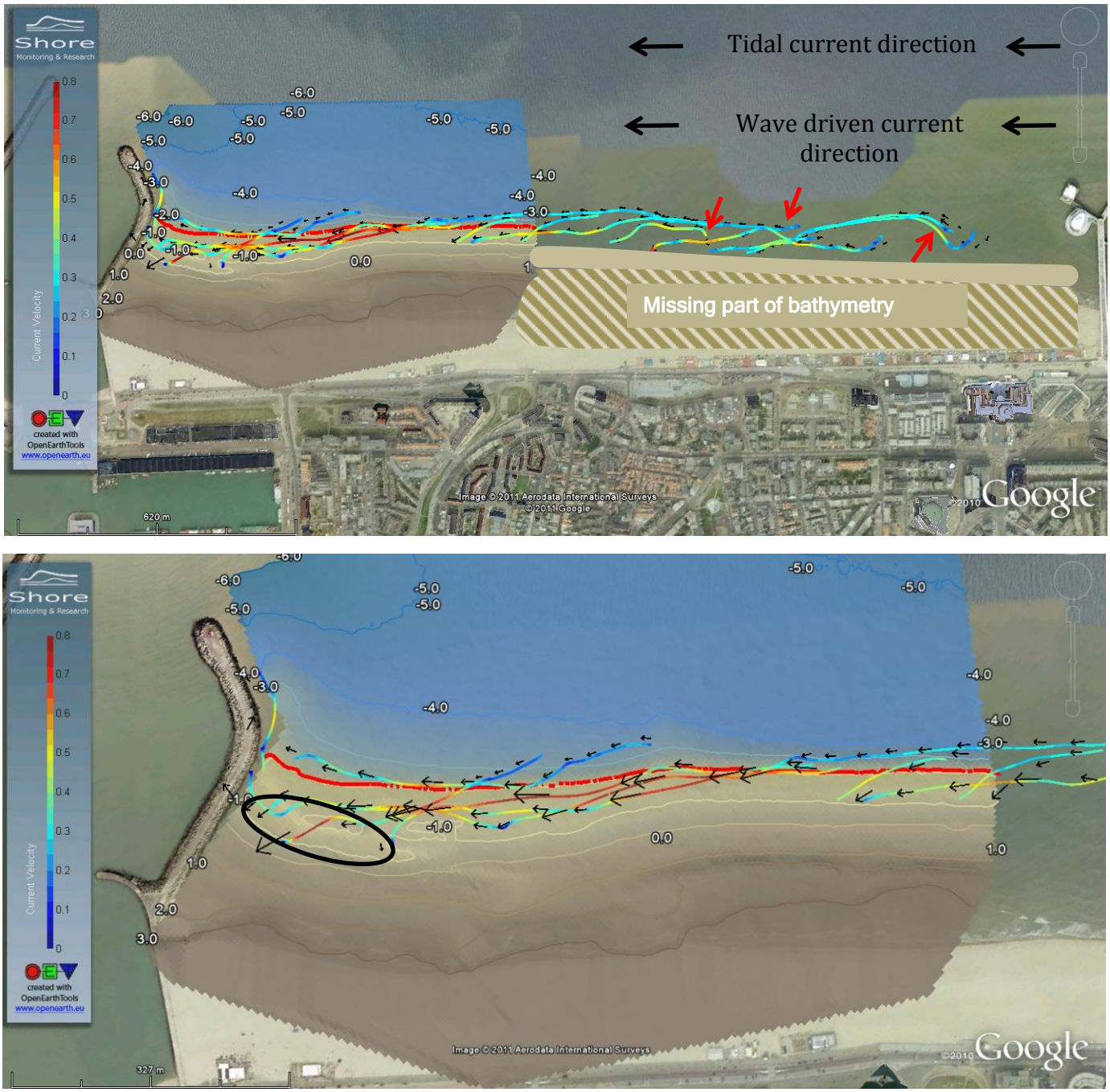



**Fig. 4.6:** Drifter trajectories April 16th 2010 AM. Colours indicate velocity along trajectory in m/s. Red line indicates approximate breaker line. Blue/grey shading and contours indicate bottom elevation in m NAP. **Top:** Complete deployment. **Bottom:** Zoom in on gradient and harbour jetty. Missing bathymetry in northern part. The beige shaded line indicates approximate shoreline position around -0.6 m NAP.

The afternoon experiment was conducted between the gradient in the beach and harbour jetty (Figure 4.7). A similar current pattern was measured as in the morning, though now during high tide instead of low tide. Still the current outside the surf zone is directed southward and is quite strong. The maximum, mean and standard deviation are 0.62, 0.32 and 0.18 m/s respectively. The strongest current was measured along the gradient, close to the beach face, until the feeder current in the trough leading to the rip along the jetty. Maximum, mean and standard deviation in the surf zone along this part of the beach are 1.30, 0.67 and 0.21 m/s respectively. Velocities in the rip current along the harbour jetty are 0.59, 0.29 and 0.09 m/s (maximum, mean and standard deviation resp.), which is about half of the current velocity in the feeder and along the gradient. The extent of the rip is limited between the length of the jetty itself and O(100 m) beyond it. Hence drifters caught in the rip along the harbour jetty exited the surf zone. The rest of the drifters beached.

Photo 4.9 is a webcam image around the end of the afternoon deployment, presented as extra context of the measurement conditions in the afternoon.

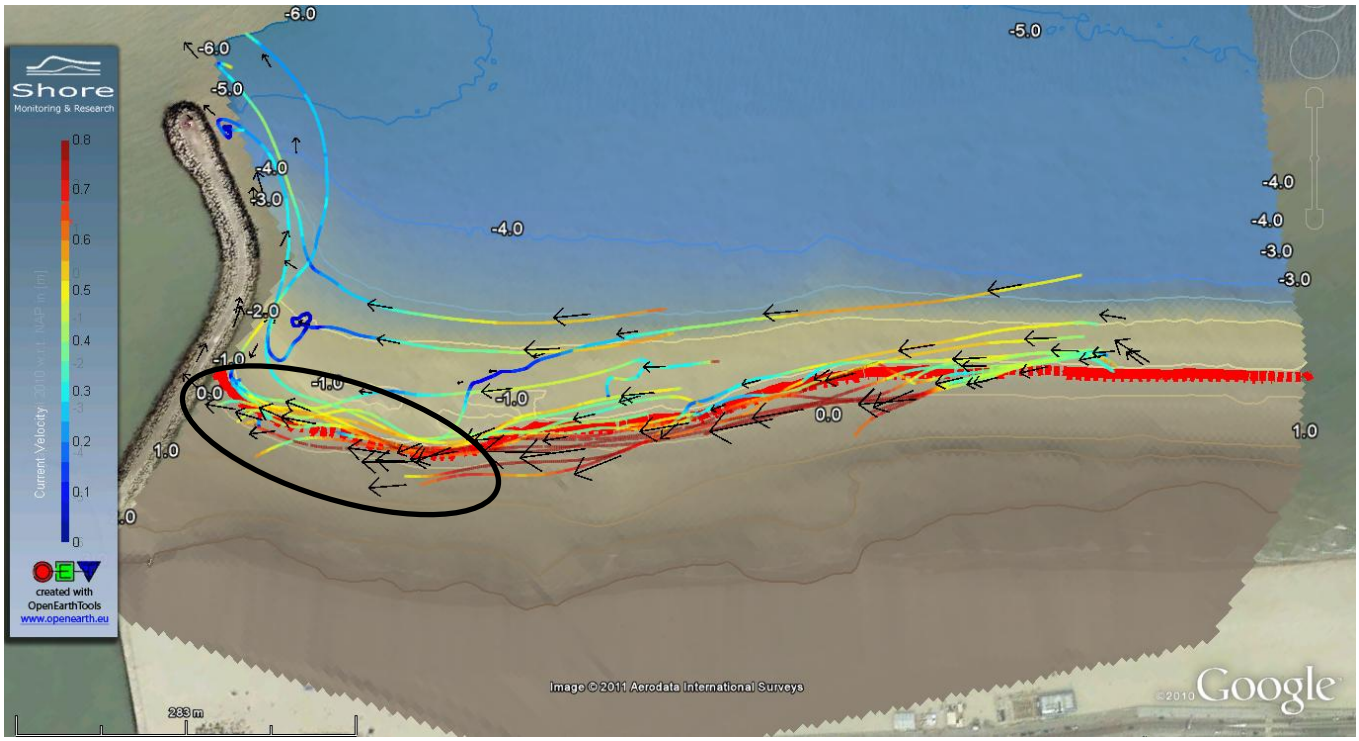



**Fig. 4.7:** Drifter trajectories April 16th 2010 PM. Colours indicate velocity along trajectory in m/s. Red dotted line indicates approximate breaker line. Blue/grey shading and contours indicate bottom elevation in m NAP.

The July experiments show the current pattern on the nourished open beach for two very different weather and wave conditions (Figure 4.8 - 4.12). On the 13th with shore normal orientated conditions and on the 16th with strong side shore orientated conditions.

Rip currents were observed on the open beach in the morning deployment of the 13th of July (Figure 4.8 and 4.9). The oblique rip current (Rip 1) was stronger than the straight offshore directed rip current (Rip 2) with maximum velocities of 0.37 m/s and 0.23 m/s respectively. The drifters in the oblique rip exited the surf zone and where retrieved approximately 200 m outside the surf zone. The drifters caught in Rip 2 exited the surf zone, but re-entered at the next bar along shore. A very weak southward directed longshore current was measured outside the surf zone (ebb tidal current O(0.10 m/s)). The longshore current inside the surf zone was both north- and southward directed depending on the location along the beach. Maximum (longshore) current velocities were measured in Trough 1 which feeds Rip 1. Maximum cross shore velocities were measured in the rip near groyne 45. The current follows the rip channel and deeper troughs around the groyne very well. Wave breaking on the bar in front of the groyne, maintains the drifters in the surf zone. The current velocity in the oblique Trough 2 leading to deeper water is comparable to Rip 2. The drifters exited the surf zone through this trough, but re-entered further south.
Generally, all drifters moved onshore over bars, side shore through troughs and offshore through channels or oblique troughs.

**Table 4.4:** Maximum, mean and standard deviation of velocities in different areas along the beach.

| Velocity | 13th July AM Low tide max - mean - std (m/s) | 13th July PM Falling tide max - mean - std (m/s) |
|---|---|---|
| Rip 1 | **0.37** - 0.20 - 0.06 | - |
| Trough 1 | **0.40** - 0.32 - 0.06 | - |
| Rip 2 | **0.23** - 0.13 - 0.06 | - |
| Trough 2 | **0.25** - 0.13 - 0.06 | - |
| Rip groyne 45 | **0.41** - 0.28 - 0.06 | **0.42** - 0.35 - 0.04 |
| Tidal current | **0.19** - 0.10 - 0.03 | **0.27** - 0.12 - 0.04 |
| Mini HW Rip | - | **0.85** - 0.40 - 0.23 |

The afternoon deployment of the 13th of July (Figure 4.10) started just after high water. No rip activity was observed along the open beach other than a narrow rip channel that discharged the water of the large trough on the high water berm into the swash (Mini HW Rip, Figure 4.10, dashed ellipse).
A cross shore array was set up, at the location where the oblique rip current was measured at low tide in the morning. No rip current was measured. Instead an alongshore current was measured with a maximum, mean and standard deviation of 0.27, 0.12 and 0.004 m/s resp. When the tide dropped below MSL, the rip current near groyne 45 was measured again. It was still present (Figure 4.11) and quite strong, just as in the morning. No wave breaking occurred on the bar in front of the groyne (as indicated by the approximated surf zone edge). Consequently, the rip current extends beyond the breaker bar, which it was limited to in the morning (Figure 4.8 - 4.9). The drifters exited the surf zone here, not to re-enter again. The trough south of the groyne doesn't seem to influence the current pattern.

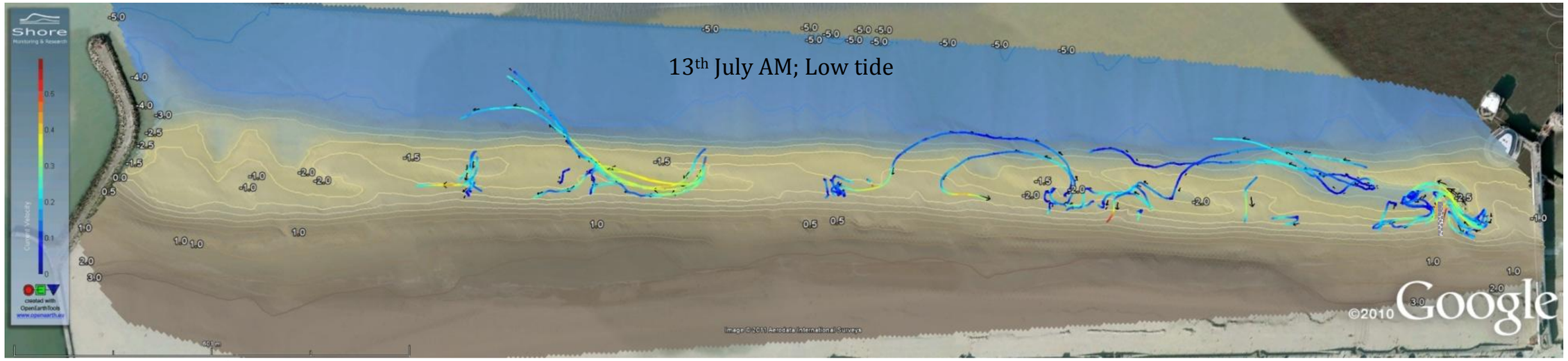



**Fig. 4.8:** Drifter trajectories July 13th 2010 AM: Rip currents on open beach and groyne 45. Colours indicate velocity along trajectory in m/s. Blue/grey shading and contours indicate bottom elevation in m NAP.

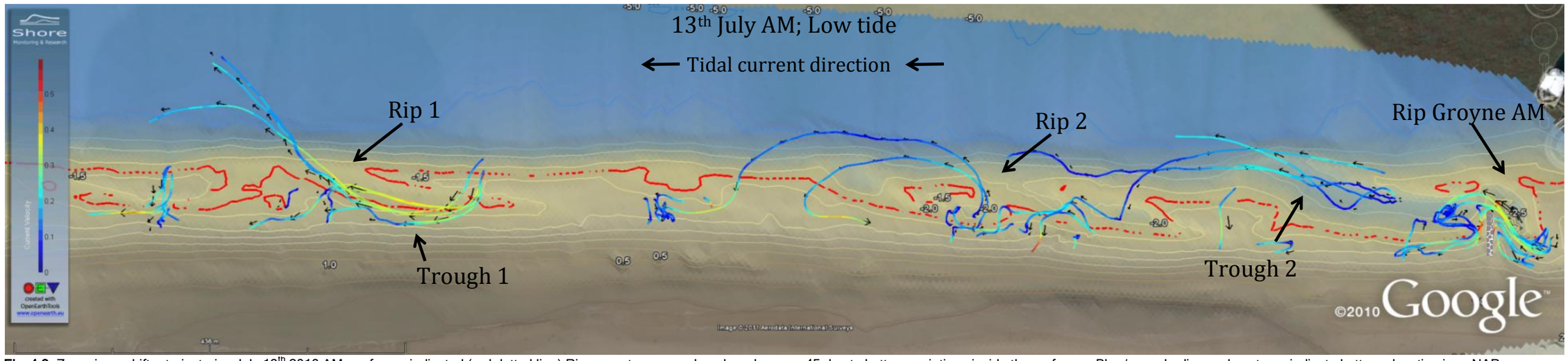



**Fig. 4.9:** Zoom in on drifter trajectories July 13th 2010 AM, surf zone indicated (red dotted line).Rip currents on open beach and groyne 45 due to bottom variations inside the surf zone. Blue/grey shading and contours indicate bottom elevation in m NAP.

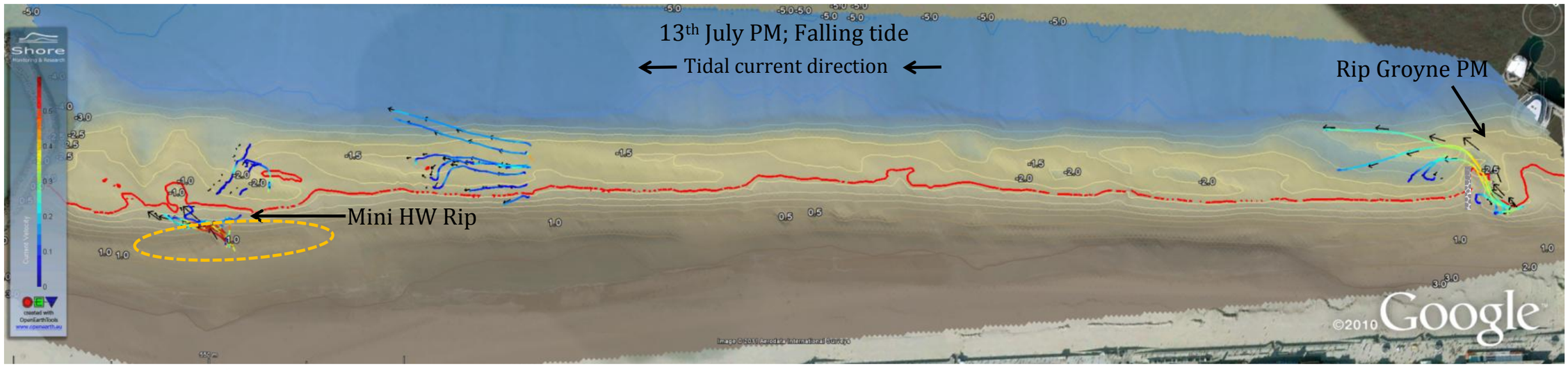



**Fig. 4.10:** Drifter trajectories July 13th 2010 PM: NO rip currents on open beach due to no bottom variations inside the surf zone (red dotted line). Still rip current near groyne 45. Colours indicate velocity along trajectory in m/s. Blue/grey shading and contours indicate bottom elevation in m NAP.

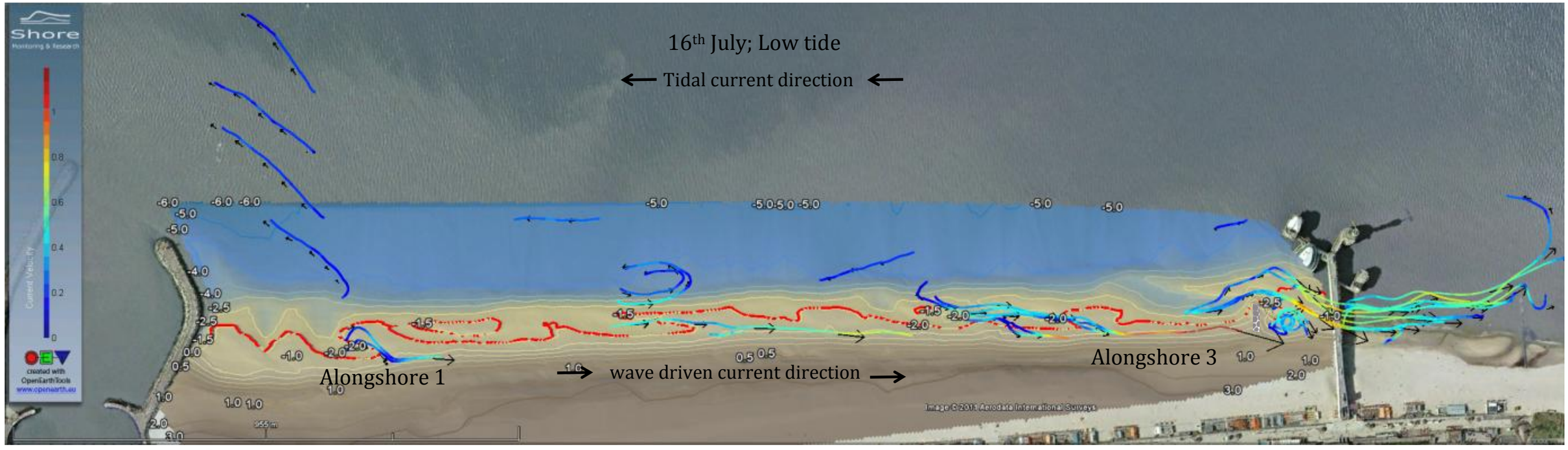



**Fig. 4.11:** Drifter trajectories July 16th 2010: **No** rip currents on open beach. Strong longshore current in surf zone, opposite directed tidal current outside the surf zone. Rip currents and eddy near groyne 45-46. Colours indicate velocity along trajectory in m/s. Blue/grey shading and contours indicate bottom elevation in m NAP.

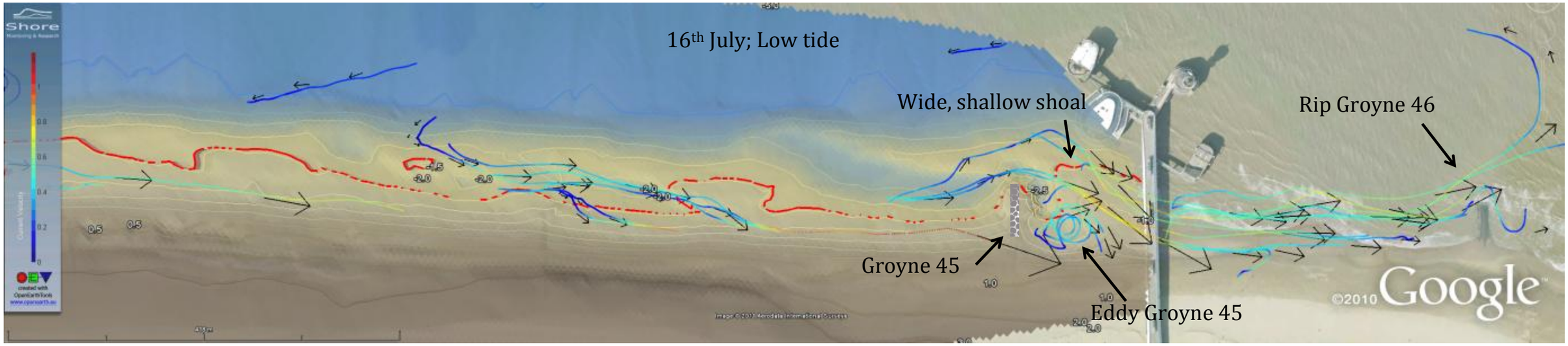



**Fig. 4.12:** Zoom in on drifter trajectories July 16th 2010: No rip currents on open beach. Rip currents and eddy near groyne 45-46. Blue/grey shading and contours indicate bottom elevation in m NAP.

On the 16th of July, a strong longshore orientated current was measured along the open beach (Fig. 4.11). No rip currents were measured on the open beach. The maximum observed alongshore velocities in the surf zone between the harbour jetty O(0.5 m/s) and groyne 45, south of the pier O(1.3 m/s), reveal how fast the longshore current can develop without groynes to decelerate it. The trajectories of the drifters between the harbour and groyne 45 seem to follow the oblique troughs in the surf zone, until they wash up in the swash. Drifters deployed outside the surf zone didn't enter the surf zone. They were transported south by the tidal current O(0.2 m/s), in opposite direction of the strong side shore wind (SW, U=9m/s) .
On the leeside of groyne 45 an eddy was measured with offshore directed current velocities varying between 0.4 to 0.5 m/s. All drifters remained in the surf zone at this location. The longshore current in the trough south of groyne 45 O(0.30 m/s) accelerates around the tip of the groyne and over a wide shallow shoal underneath the pier O(0.6 ms/s). At the next groyne (46) a strong rip current with a maximum velocity of 0.70 m/s and an offshore extent of more than 200 m was measured. The drifters caught in this rip exited the surf zone, not to re-enter again.

Figure 4.12 is a close up of the transition from the open beach without groynes to a beach with groynes. It is a perfect showcase of the current pattern along an open beach versus the current pattern along a beach with groynes under the same conditions. A strong longshore orientated current pattern (without rip currents!) was observed along the open beach while at the groynes eddies and strong rips were observed. It also shows that groynes do decelerate the current efficiently. The longshore current has decreased quite dramatically from O(1m/s) on the open beach to O(0.20 m/s) beyond groyne 46. Furthermore, the maximum current velocities on the open beach were observed close to the waterline, whereas beyond groyne 45 velocities are minimal at the waterline and maximum around the tip of the groynes.

**Table 4.5:** Maximum, mean and standard deviation of velocities in different areas along the beach.

| Velocities 16th July | max - mean - std (m/s) |
|---|---|
| Alongshore in surf zone open beach 1 | **0.52** - 0.25 - 0.11 |
| Alongshore in surf zone open beach 2 | **0.72** - 0.47 - 0.11 |
| Alongshore in surf zone open beach 3 | **1.31** - 0.35 - 0.21 |
| Alongshore in trough south 45 | **0.43** - 0.29 - 0.07 |
| Alongshore shoal under pier | **0.90** - 0.61 - 0.15 |
| Alongshore pier - groynes 45 - 46 | **0.76** - 0.42 - 0.17 |
| Alongshore past groyne 46 | **0.50** - 0.20 - 0.11 |
| Offshore directed velocity eddy groyne 45 | **0.54** - 0.46 - 0.04 |
| Rip groyne 46 | **0.70** - 0.51 - 0.11 |
| Tidal current (opposite direction) | **0.33** - 0.17 - 0.05 |

*4.7.2 Conclusions current pattern observations*
Three distinct nearshore current patterns were observed in the experiments:

- if groynes were present and emerged from the water surface: rip currents near groynes were observed for all measured conditions
- strong alongshore orientated current pattern, without rip currents along the open nourished beach during oblique wave incidence and side shore wind (April and July 16th, Figure 4.6-4.8 and Figure 4.11-4.12 respectively)
- rip currents along the open nourished beach during shore normal incident, fairly long crested, regular waves and calm wind conditions. But **only** in combination with vertical variations in bottom topography within the surf zone (July 13th AM, Figure. 4.8 and 4.9). For comparable conditions, without vertical variation in bottom topography within the surzone no rips were observed on the open beach (July 13th PM, Figure. 4.10).

Inside the surf zone, the drifters follow the wave driven current. Onshore movement occurs mainly over bars and shoals (Figure 4.6 - Figure 4.9) or through oblique troughs (Figure 4.12). Offshore movement, if any, occurs in depressions in the inter- and sub tidal area, channels in between bars (Figure 4.8) and next to groynes. Dominant longshore movement occurs along the out- and inside of bars and in troughs between breaker bar and beach face.
Outside the surf zone the tidal current dominates (also over strong wind from the opposite direction) in both longshore directions depending on the tidal phase.

Maximum longshore current velocities on the open beach were measured along gradients in the coastline and in the inner part of the surf zone (close to the waterline), diminishing towards the outer edge of the surf zone. For parts of the beach with groynes the opposite holds. Maximum offshore current velocities were measured in rip currents near coastal structures. Offshore current velocities in rip currents between bars or in oblique troughs were observed to be weaker by approximately 20 to 25%. Maximum onshore velocities were observed over bars and shoals.

Rip current activity near groynes was observed for water level elevations around and below NAP in all experiments. On the open beach rip currents have been observed for nearly shore normal incident, longer period waves and mild (offshore) wind conditions. But only in combination with vertical variations in bottom topography within the surf zone (July 13th AM,. Low tide). Around high tide the current pattern seems to be less influenced by groynes and surf zone bottom topography (April PM and July 13th PM measurements), No rips were observed in these experiments.

Surf zone exits occurred predominantly for drifters caught in a rip current near coastal structures which extended beyond the surf zone and to a smaller extent in rip currents between bars if no waves were breaking close to the edge of the rip. See measurements near groyne 45 and groyne 46 in July (13th and 16th). Furthest offshore transported drifters O(>100 m) were the ones that exited the surf zone in a rip current at times of opposite tidal and wave driven current directions. Drifters caught in rips at times of coinciding tidal and wave driven current direction stayed closer to the surf zone edge or even re-entried further alongshore. The maximum observed offshore extent of the rip currents near coastal structures is approximately 200m (roughly twice the length of the groynes), But for most experiments between O(10 m) and O(50 m) beyond the groyne tip or surf zone edge. Surf zone re-entries only occurred occasionally during the experiments. Most of the re-entries occurred for drifters that skirted the surf zone edge in experiments where tidal current and wave driven current direction coincided. For opposite tidal and wave driven current direction no re-entries were observed (July 16th). The few surf zone re-entries indicate that when caught in a rip current the chances of being transported back to the beach from well outside the surf zone are slim if no waves are breaking close to the edge of the rip.

### 4.8 Analysis of drifter data

The current pattern observations suggest a certain regime for the occurrence of rip currents on the open beach. Rip currents were observed during low to mid tide when waves were almost normally incident and vertical variations in bottom topography were present within the surf zone (Table 4.1, Figure 4.8 – 4.9, July 13th AM). No rip currents were observed on the open beach in any tidal phase, when wind and waves were obliquely incident (Table 4.1, Figure 4.6-4.7, 4.10-4.12). Instead a strong longshore current within the surf zone was observed which is most clearly illustrated by the April and July 16th experiments.

To reveal whether a significant greater part of movement exist in the cross shore or longshore direction per experiment, the distribution of longshore and cross shore drifter movement along the open beach is analysed per experiment.

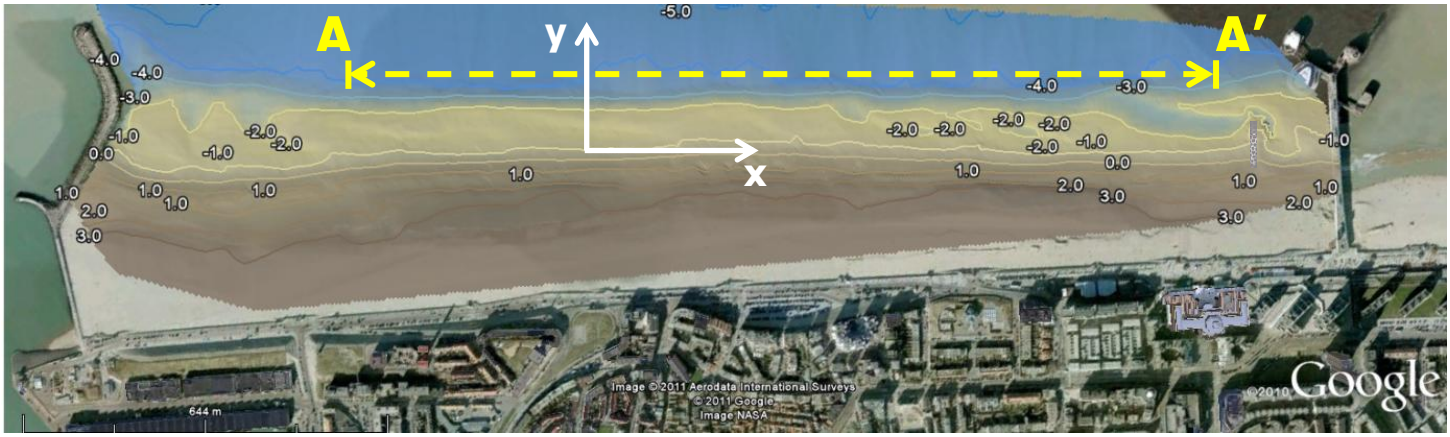



**Fig. 4.13:** Area for detailed drifter velocity analysis, indicated by dashed yellow line A-A' on July bottom topography in blue/grey shading and contours in m. Local alongshore (x) and cross shore (y) coordinate system indicated in white solid lines.

#### 4.8.1 Longshore versus cross shore movement

Only measurements between A and A' (Figure 4.13, yellow line) are used. This excludes the area next to coastal structures from the analysis. Secondly, only absolute current velocities greater than 0.15 m/s are taken into account. Smaller velocities are a) less reliable because of the accuracy of the GPS drifters, especially for directions, and b) not relevant for swimmer safety. Drifter positions were transformed to alongshore (x) and cross shore (y) coordinates (Figure 4.13). The directional domain of 360° is divided into bins of 2°. Drifter direction and corresponding velocity in that direction per time step are plotted in histograms. The histograms are normalised with respect to the total amount of observations per experiment. Because of the small bin size the y-axis of the histograms don't provide insight in a clear percentage of the amount of time of drifter movement in a specific direction. However, the histograms do reveal dominant drifter movement in alongshore or cross shore direction, which is the objective. The colours in the bars indicate the absolute drifter velocities corresponding to the values shown in the legends (note the different legend scale). The results are plotted in (Figure 4.14- 4.15).

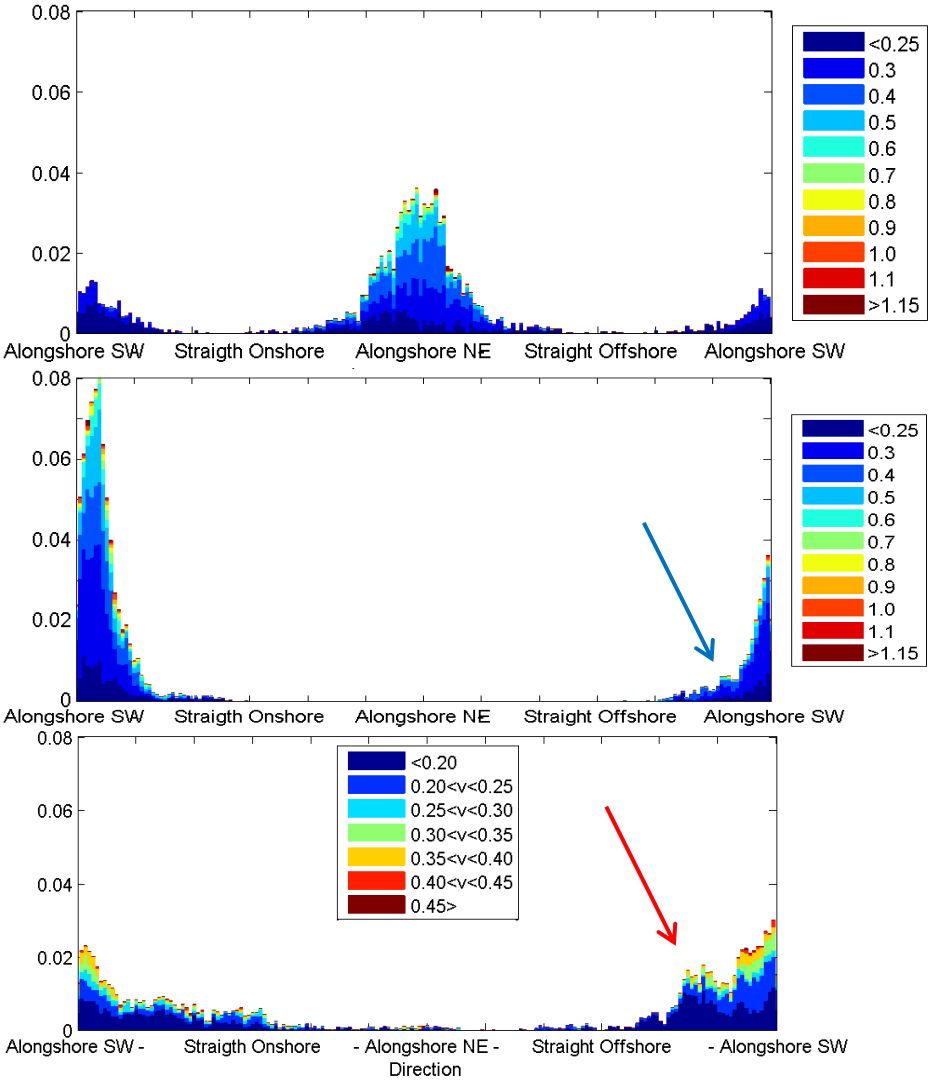
The top panel of Figure 4.14 shows the normalised distribution of all drifter velocity directions and magnitudes for the experiment of the 16th of July. Strong side shore wind (*SW*, *U* = 10 m/s) and obliquely incident waves (*H* = 1.6 m, *T* = 5.4 s) caused a NE directed wave driven current. The ebb tidal current acted in the opposite direction. The plot clearly illustrates the corresponding dominantly longshore orientated current pattern, with the highest velocities in the direction of the wave driven current and hardly any shore normal drifter movements. The observations around the alongshore SW direction correspond to the ebb tidal current direction which is much weaker than the wave driven current in alongshore NE direction.

**Fig. 4.14:** Normalised distribution of drifter velocity direction and magnitude.

**Top:** July 16th, strong SW wind and SW waves. High wave driven current velocities in alongshore NE direction and opposing weaker tidal current velocities in alongshore SW direction. Hardly any offshore directed velocities.

**Middle:** April 16th, wind and waves from the North. Coinciding tidal and wave driven current direction show dominant alongshore SW directed velocities. Hardly any cross shore movement is observed. Blue arrow indicates occasional oblique rip.

**Bottom:** July 13th, shore normal incident waves, mild offshore wind and low tide. Current velocities are lower (note the legends in the different panels) and more distributed over the directional domain. Observation around the offshore directions indicate rip currents. Oblique offshore directed currents with considerable velocity magnitude are observed in the bottom panel indicated with the red arrow.




The experiments of April 2010 were also performed with oblique incident waves and wind. This time from the North, causing a wave driven current towards the SW. The tidal current was also SW directed. The middle panel of Figure 4.14 shows the normalised distribution of drifter velocity direction and magnitude for both April experiments (AM and PM). The plot clearly reveals dominant longshore, slightly onshore directed movement of the drifters. Some obliquely offshore directed (rip) currents are revealed and indicated by the blue arrow. The highest velocities are observed in alongshore direction.

In contrast to the experiments performed with oblique wave and wind incidence, the bottom panel of Figure. 4.14 reveals a wider spread in drifter directions for the experiment of the 13th of July and much lower drifter velocities in general. Nearly shore normal approaching, regular waves from the NNW and negligible offshore wind prevailed. The ebb tidal current was directed towards the SW. The plot illustrates a less dominantly one directional current pattern. The majority of the observations is in the direction of the weak tidal current (alongshore SW). But, compared to the middle and top panel of Figure 4.14, there are quite a lot of observations in onshore and offshore directions.

*4.8.2 Conclusions longshore versus cross shore movement*

The histograms in Figure 4.14 substantiate the hypothesis that for obliquely incident waves and wind, the current pattern is dominated by a strong longshore directed current. A significant greater part of the drifter movements is observed in longshore direction, shown by the top and middle panel of Figure 4.14. For nearly shore normal incident waves and negligible wind the longshore current is weak, overall velocities are smaller, and drifter movements are spread out over the directional domain. The bottom histogram shows a significant larger part of offshore directed currents than the other histograms.

*4.8.3 Velocities in the cross shore profile*

One of the questions to be answered in this chapter is **in which part of the nearshore strong longshore currents** and **in which part strong cross shore currents occur**. Therefore measured drifter velocities are plotted over the water depth. Positive cross shore velocities are offshore directed. Positive longshore velocities are in NE alongshore direction (see coordinate system in Figure 4.13). The water depth is approximated by the measured local bottom elevation and measured water level elevation in the port of Scheveningen. Wave set up isn't accounted for. Extra information on drifter position in the nearshore is obtained by indicating whether the drifter was near the beach face (red), on the inside of the breaker bar (blue) or outside of the breaker bar and further offshore (cyan). This could reveal whether certain parts of the cross shore or particular water depths correlate to strong or weak current velocities. The division of the cross shore profile is plotted in Figure 4.15. Regions of wave breaking are indicated by the grey line and shaded area in the plots, based on the breaker depth as determined in section 4.6.

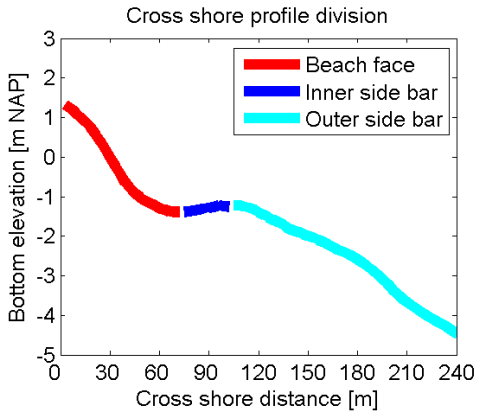



**Fig. 4.15:** Cross shore profile division to indicate drifter position; beach face (red), inner side of the bar (blue) and outer side of the bar (cyan).

Comparing the velocity distributions will also reveal the ratio of the longshore and cross shore velocity magnitudes in the cross shore. Combined with the current pattern observations (section 4.7.2), this could provide **insight into the occurrence of rip currents in relation to the longshore current**.

First the results for the experiment of the 16th of July (waves and wind from the SW) are discussed. Figure 4.16 shows two cross shore distributions; the longshore velocities on the left and the cross shore velocities on the right. (N.B.: Note the values on the x-axis). First observation are the high longshore drifter velocities on the beach face, where waves are breaking (Figure 4.16 left panel). The cross shore velocities of the drifters in this part of the profile are significantly smaller (compare drifter velocities on the beach face in left panel with right panel). The left panel shows a local maximum in longshore current velocity just onshore and offshore from the deepest part of the trough, but still in considerable water depths of 1.5 to 1.75 m. Figure 4.16 also reveals that for an equal water depth, of approximately 1 m, on the in- and outside of the breaker bar, the longshore current is stronger on the inside of the bar than on the outside of the bar or beach face. The absolute maximum longshore current velocity was observed at the top of the beach face in very shallow water. In water depths larger than 3.25 m, the tidal current dominates in southward direction, which is opposite to the wave driven current direction. The right panel (cross shore velocities) show mostly (small) positive velocities on the inside of the breaker bar and on the beach face: meaning onshore movement of the drifters. Directly on the other side of the breaker bar, offshore movement is

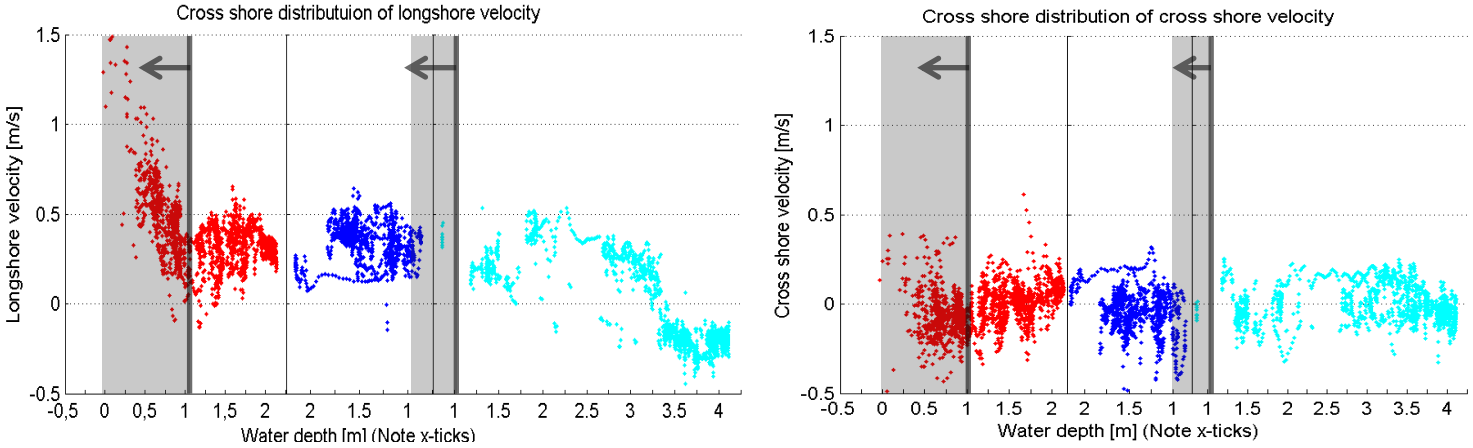



**Fig. 4.16 Left:** Cross shore distribution of **longshore drifter velocities** for 16th July experiment along the open beach.
**Right:** Cross shore distribution of **cross shore drifter velocities** for 16th of July experiment along the open beach. Positive cross shore velocities are offshore directed.

revealed in the plot. This corresponds to drifters slowly moving further away from the surf zone into the tidal current. This is not rip current related, but due to the fact that the drifters were released on the edge of the surf zone; an area of lateral mixing of the opposing tidal and wave driven current.

Fig. 4.17 shows the cross shore distribution of the longshore current velocity of the experiment of July 13th on the left and the cross shore distribution of the cross shore velocities on the right. Nearly shore normal incident, longer period waves and mild (offshore) wind conditions prevailed on this day. First observation is that the long- and cross shore velocities are of the same order of magnitude. A remarkable observation are the feeder currents (Figure 4.17 left panel) which are revealed by the slightly higher longshore current velocities in both alongshore directions. These currents flow to deeper parts of the surf zone, where no waves are breaking and feed the rip current. On the breaker bar, longshore current velocities are near zero. The right panel is very interesting. On the breaker bar (first region of wave breaking in this experiment) only onshore current velocities are observed. In the deeper parts within the surf zone (no wave breaking) offshore directed current velocities are observed (rips). On the beach face rip currents and onshore directed velocities are observed. Both distributions shown in Figure 4.17 indicate a current pattern within the surf zone which is topographically controlled for these conditions and hence no dominant longshore current in one direction. During this measurement rips were observed along the open beach.

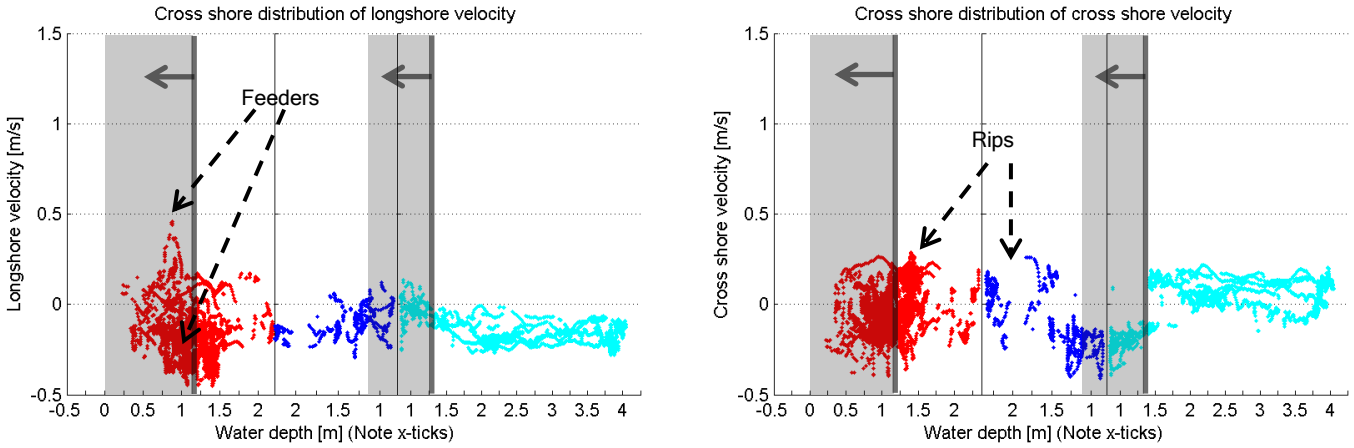



**Figure 4.17 Left:** Cross shore distribution of **longshore drifter velocities** for July 13th experiments along the open beach.
**Right:** Cross shore distribution of **cross shore drifter velocities** for July 13th experiments along the open beach. Positive velocities are offshore directed.

The April experiments were performed within two months after construction of the nourishment. The cross shore profile of the beach is shown in Figure 4.18. No breaker bar and trough had developed since the nourishment. Keeping the same division of the cross shore profile to add information on drifter position, all drifter velocities are represented by red markers.

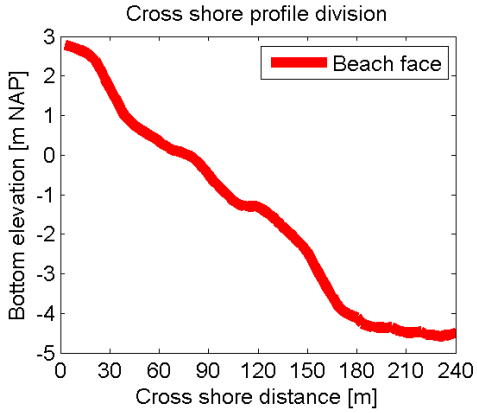



**Fig. 4.18:** Cross shore profile division to indicate drifter position; beach face (red), inner side of the bar (blue) and outer side of the bar (cyan).

The two experiments performed on April the 16th (morning and afternoon) are described separately. Waves and wind were obliquely incident from the North for both experiments and slightly more energetic in the second. The morning experiment was performed around low tide; the afternoon experiment around high tide (see Table 4.1).

Figure 4.19 shows the cross shore distributions of the longshore (left) and cross shore velocities (right) of the morning experiment. Note that the longshore current velocities are significantly higher than the cross shore velocities. Ebb tidal current and wave driven current were both directed alongshore to the southwest as shown clearly by only negative velocities in the left panel of Figure 4.19. Longshore drifter velocities are highest within the surf zone in water depths smaller than 1.25 m, reaching 0.75 m/s quite frequent. The cross shore velocities are mostly onshore directed (right panel). Though occasional weak offshore directed current velocities are observed.

Figure 4.20 shows the results for the afternoon deployment of April 16th. Although the flood tidal current should be directed northward (which would mean positive longshore directed velocities), only southward directed movement was observed. Again the longshore velocities within the surf zone are significantly higher than in other parts of the cross shore and most important: significantly higher than the cross shore velocities. In general cross shore current velocities are weak and onshore directed. No rips currents were observed in these measurements.

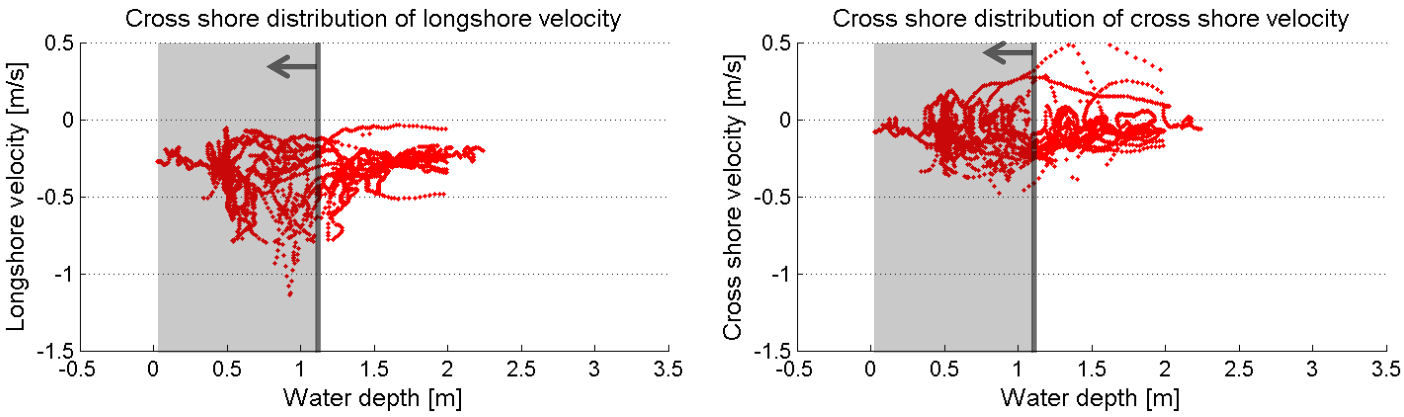



**Figure 4.19 Left:** Cross shore distribution of **longshore drifter velocities** for April 16th AM experiment along the open beach.
**Right:** Cross shore distribution of **cross shore drifter velocities** for April 16th AM experiment along the open beach. Positive velocities are offshore directed.

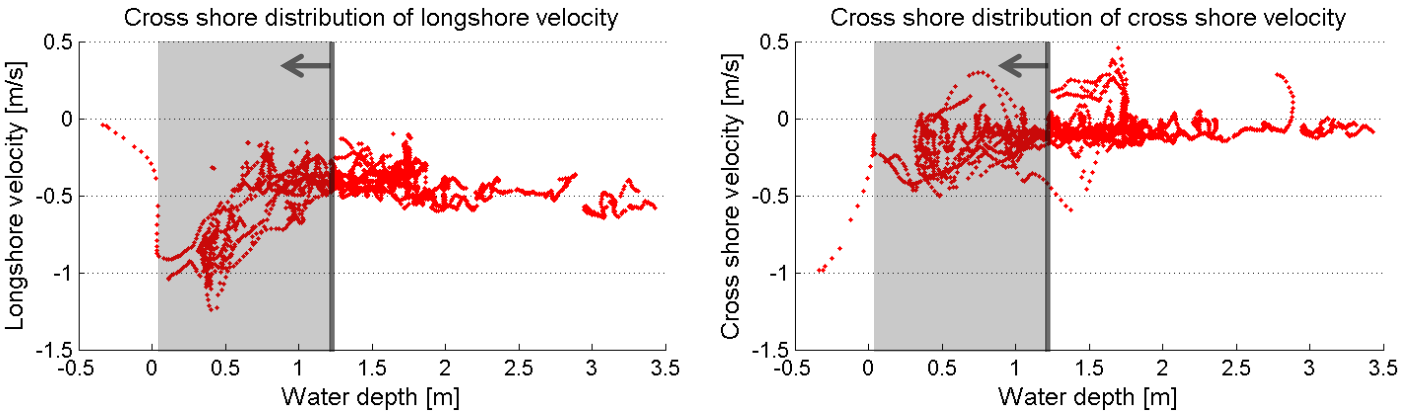



**Figure 4.20 Left:** Cross shore distribution of **longshore drifter velocities** for April 16th PM experiment along the open beach.
**Right:** Cross shore distribution of **cross shore drifter velocities** for April 16th PM experiment s along the open beach. Positive velocities are offshore directed.

*4.8.4 Conclusions velocities in the cross shore profile*

For the experiments with oblique wave and wind incidence the longshore current velocities within the surf zone are significantly higher than the cross shore velocities: O(0.50 m/s) and O(0.10 m/s) respectively.

Maximum longshore current velocities O(1 m/s) were generally observed on the beach face within the surf zone in water depths of 1 m or less. When a breaker bar was present in the surf zone, a second local maximum in longshore current velocity O(0.5 m/s) is observed just onshore and offshore of the deepest part of the trough between the beach and breaker bar in considerable water depths of 1.5 to 1.75 m. On the (outside of the) breaker bar the longshore current velocities are generally very small O(0.10 m/s). Further offshore the longshore velocities are in the order of 0.3 m/s depending on the tidal phase.

Maximum cross shore current velocities are observed within the surf zone in onshore direction, over the shallow parts of the cross shore, on the inside of the breaker bar and on the beach face. In the trough and further offshore the cross shore velocities are near zero. For these conditions the current pattern is dominated by a strong wave driven alongshore current. Vertical variations in bottom topography within the surf zone only caused an onshore component in drifter velocities. When waves were incident at angles larger than 20°, no rips where observed. For slightly less oblique waves, angles between 10° to 20°, occasional rips were observed.

For the experiment with nearly shore normal incident, longer period waves and negligible wind, the longshore and cross shore velocities within the surf zone were of the same order of magnitude. Moreover, longshore current velocities within the surf zone were observed in both south and northward direction. In the trough between breaker bar and beach face longshore current velocities of up to O(0.45 m/s) were observed in water depths of approximately 1 m. These are associated with the feeder currents of (oblique) rips and can be hazardous to swimmers. Outside the surf zone longshore current velocities are in the direction of the tidal current and during the experiment very weak O(0.10 m/s).
Regarding the cross shore currents within the nearshore, very distinct areas of onshore and offshore current velocities are revealed. On the breaker bars (thus within the surf zone) only onshore directed velocities are observed O(0.3 m/s). Offshore directed current velocities O(0.25 m/s) are predominantly observed in the deeper parts of the surf zone O(1.25 – 2 m).
For these conditions, no dominant alongshore wave driven current is generated. The current pattern is topographically controlled. Vertical variations in bottom topography within the surf zone control wave breaking and consequently determine the current pattern within the surf zone.

### 4.9 Conclusions

Three distinct nearshore current patterns were observed in the experiments:

- rip currents near emerged groynes for all measured conditions
- rip currents along the open nourished beach during shore normal incident, fairly long crested, regular waves and calm wind conditions. But **only** in combination with vertical variations in bottom topography within the surf zone. For comparable conditions, without vertical variation in bottom topography within the surf zone no rips were observed on the open beach.
- strong alongshore orientated current pattern, without rip currents along the open nourished beach during oblique wave incidence and side shore wind

*Rips near groynes*
Rip currents near emerged groynes and harbour jetties were measured in all experiments and therefore assumed to be permanently present next to these structures (when emerged) due to any longshore current or wave breaking in between these structures. Velocities in these rips are generally twice the magnitude of the average longshore (wave driven) current velocity and increase in strength and extent with increasing wave or tidal driven alongshore currents. When the wave and tidal driven current act in opposite alongshore direction, the offshore extent of the rip current originating next to these structures can be as far as several hundred meters. This is very hazardous for bathers. When the wave and tidal driven current act in the same alongshore direction, the extent of the rip current originating next to these structures, is limited to the tip (contour) of the structures or O(50 m) beyond it. The tidal current deflects the rip current in alongshore direction. These rips are also hazardous for bathers.

*Rips on open beach*
Along the open beach, rip currents were only observed during nearly shore normal incident, longer period waves and mild (offshore) wind conditions at locations within the surf zone where vertical variations in bottom topography were present. Under these circumstances long- and cross shore current velocities were of the same order of magnitude. No dominant longshore current direction was observed within the surf zone. The current pattern is topographically controlled; the variations in the bottom topography within the surf zone control wave breaking, and consequently the current pattern.
On the breaker bars only onshore directed current velocities were observed O(0.30 m/s). In the deeper (rip) channels offshore directed velocities were observed O(0.25 m/s). In the troughs within the surf zone, the longshore current was directed both in south and northward alongshore direction sometimes with a considerable offshore component associated with the feeder currents (O(0.45 m/s)) of a rip current.
The direction of the rip currents on the open beach varied between 45° to 90° offshore. The oblique rips were stronger than the straight offshore directed rips; O(0.45 m/s) and O(0.25 m/s) respectively. The oblique rip was related to a strong feeder current in an oblique trough. The offshore extent O(>100 m) was quite large. The extent of the straight offshore directed rip was smaller O(10 m) beyond the edge of the surf zone.

*No rips on open beach*
No rip currents were observed along the open beach when oblique waves and wind prevailed. For these conditions the current pattern within the surf zone is dominated by a strong longshore current in the direction of wave breaking, generated by the obliqueness of wave incidence (amongst others). For increasing oblique wave incidence, increasing longshore current and decreasing cross shore current velocities were observed. The longshore current velocities within the surf zone were observed to be at least three times as high as the cross shore velocities in the surf zone during the experiment with wave angles larger than 20°. Vertical variations in bottom topography within the surf zone only caused a weak onshore directed component in the otherwise dominantly longshore orientated current.

Neither were rip currents observed on the open beach when no vertical variations in bottom topography were present within the surf zone, either due to the morphology of the beach (lack of formation of breaker bar shortly after nourishment) or due to a combination of tidal level and incident wave height.

For slightly less oblique waves, angles between 10° to 20°, the current pattern within the surf zone was still dominantly longshore orientated, with an onshore component. However, the longshore current velocities were less strong (approximately twice as strong as the cross shore velocities). Occasionally very short oblique rips were observed within the surf zone.

*Longshore current on groyned and open nourished beach*
A big difference between the longshore current along a groyned and open beach is the location and magnitude of maximum current velocities. Maximum current velocities along the open beach were measured close to the beach face diminishing towards the end of the surf zone. This is contrary to the distribution of the longshore current along a beach with groynes, where maximum current velocities were observed towards the surf zone edge.
In the experiments with oblique wave and wind incidence maximum longshore current velocities O(1 m/s) on the open beach were generally observed on the beach face within the surf zone in water depths of 1 m or less. A second local maximum in longshore current velocity O(0.5 m/s) is observed just onshore and offshore of the deepest part of the trough between the beach and breaker bar in considerable water depths of 1.5 to 1.75 m. Along the groyned beach maximum alongshore velocities O(0.5 m/s) were measured towards the surf zone edge, diminishing towards the beach.

*Longshore gradients in shoreline*
Acceleration of the wave driven current was measured along the longshore gradient in shoreline orientation at the lateral boundary of the nourishment. Velocities along this gradient reached 1 m/s quite frequent. Due to the relatively mild gradient (15-20°) the longshore current didn't separate from the coastline. Possibly larger gradients would result in alongshore flow separation, accompanied with a large eddy in the lee of the gradient.
No rip current were observed along the gradient. This is due to the wave angle of incidence, which was large for the experiments along the gradient. Possibly, when waves are normally incident on the gradient, rip currents could form there. However, these conditions didn't occur during the measurements at the gradient.

*Surf zone exits and re-entries*
Surf zone exits occurred predominantly for drifters caught in a rip current near coastal structures which extended beyond the surf zone and to a smaller extent in rip currents between bars if no waves were breaking close to the edge of the rip. Surf zone re-entries only occurred occasionally during the experiments. Most of the re-entries occurred for drifters that skirted the surf zone edge in experiments where tidal current and wave driven current direction coincided. For opposite tidal and wave driven current direction no re-entries were observed. The few surf zone re-entries indicate that when caught in a rip current the chances of being transported back to the beach from well outside the surf zone are slim if no waves are breaking close to the edge of the rip.

*Rip current regime*
The above mentioned conclusions regarding the occurrence of rip currents on the open beach substantiate the hypothesis that the occurrence of rip currents on the open nourished beach is related to – and limited by- the longshore current within the surf zone. Besides wave height and wave period, the obliqueness of wave incidence with respect to the shoreline influences the generation of this current for an important part. The wave angle of incidence varies more over the measurements, than the wave height and wave period. An obvious difference in the character of the current pattern was revealed. Therefore, the wave angle of incidence is considered as a governing parameter in the occurrence of rips in relation to the longshore current. Secondly, vertical variations in bottom topography within the surf zone were revealed to be of crucial importance in the occurrence of rip currents. These bottom variations cause variations in wave breaker height alongshore, which in terms causes water level gradients and possibly rip currents. Whether rip currents occur, is determined by the combination of the above mentioned parameters. The next chapter will present conceptual models based on these parameters.

# 5 Synthesis

In a synthesis of the results of the analysis of the measurements, rescue reports and the survey amongst the lifeguards, relevant aspects of nearshore currents and beach configuration with respect to swimmer safety are presented. Secondly, two conceptual models for the occurrence of rip currents along a wind sea dominated coast are presented; one for lifeguard use on the beach and another for coastal engineering purpose.

## 5.1 Relevant swimmer safety aspects of nearshore currents and beach configuration

Measurements, reveal the importance of the longshore current in assessing swimmer safety. Commonly swimmer safety is associated with rip currents. On swell dominated coasts with large variations in bottom topography in the surf zone and small longshore currents O(< 0.2 m/s) these rips can form a great risk for bathers. However, along the wind sea dominated Delfland coast with small vertical variations in bottom topography, frequent nourishments and combined tidal, wind and wave driven alongshore currents reaching 1 m/s or more, rips are found to be only one (though still very important) part of swimmer safety.

Based on the analysis of the measurements, rescue reports and inventoried swimmer safety aspects in the survey amongst the lifeguards, seven main criteria have been formulated which need to be evaluated in order to make a comprehensive assessment of the impact of nearshore currents and beach configuration on swimmer safety at a specific site:

- Bars, troughs and rip channels
- Coastal structures
- Longshore currents
- Rip currents
- Predictability
- Profile gradients
- Alongshore gradients in shoreline

Often a combination of the criteria causes hazardous situation for bathers. The criteria will be discussed here below.

*Bars, troughs and rip channels*

- Pronounced bars, deep troughs and rip channels cutting through the bars influence the nearshore current pattern. When vertical variations between them are large the occurrence of rip currents is promoted. This will be elaborated on in the section 5.2. In general, less vertical variation in nearshore morphology will result in a safer bathing area.
- Shallow bars attract many bathers during low tide. When the shallow breaker bar is separated from the beach by a deep trough a potential dangerous situation is created in the rising tide period. Bathers who could wade to the bar during low tide, are now forced to swim through the trough (Figure 5.1). The tidal flood current or any wave driven current, will transport swimmers alongshore. When rip channels or obliquely offshore orientated troughs are present, swimmers risk to be transported offshore (Figure 5.4).
- Bathers are often not aware of rip channels in the shallow bar. When stepping into a rip channel, they suddenly have to swim. The majority of swimmers then chooses to swim back towards the beach instead of back to the bar or in alongshore direction towards the next bar (depending on current direction). A potentially dangerous situation is created. A current transporting them offshore and or alongshore will cause a panic reaction; the bather will need to be rescued.
- Shallow breaker bars also limit the striking force of the rescue brigades: their boats can get stuck on the bar, keeping them trapped in the trough during low tide.

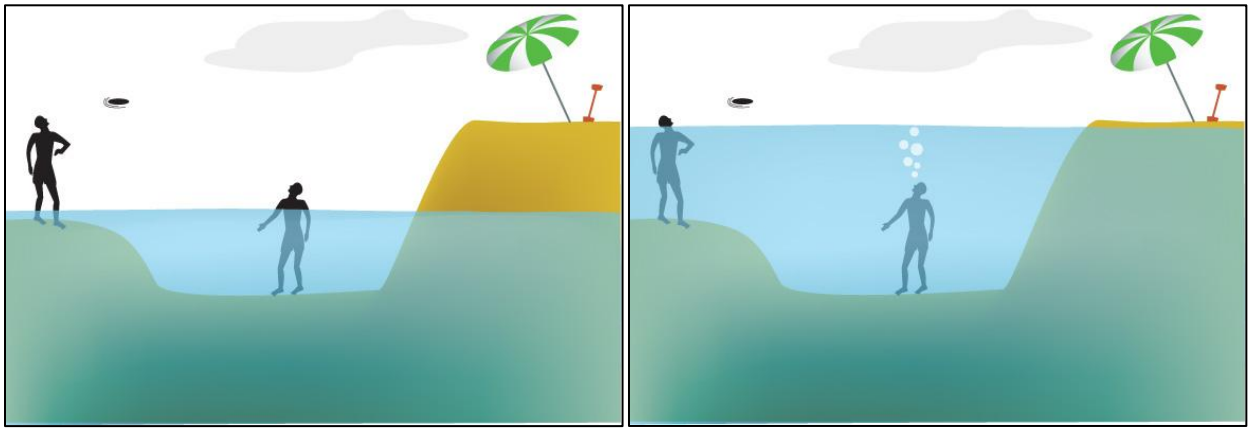


**Figure 5.1 Left:**Low tide shallow bar, wadeble trough. **Right:** High tide, filled trough, too deep to wade through, cutting off bathers on bar

*Coastal structures*

- By themselves, coastal structures like groynes or harbour jetties aren't dangerous for swimmers. But combined with wave and tidal driven alongshore currents hazardous situation can occur for bathers.
- When structures like groynes and harbour jetties are emerged above the water surface they deflect wave and tidal driven alongshore currents, invoking strong outward flowing currents (rip currents) along the upstream side of these structures and possibly eddies in the leeside, Figure 5.2.
- When only just submerged, wave and tidal driven alongshore currents can transport people over the groynes, causing injury or panic which is both negative for swimmer safety, Figure 5.3.

*Longshore current*

- The longshore current plays an important role in assessing swimmer safety. On wind sea dominated coasts, such as the Delfland coast, combined wind, wave and tidal driven longshore currents can easily attain velocities of 1 m/s or more. When groynes are present the current is decelerated and consequently less strong towards the waterline. This is beneficial for swimmer safety. However, as mentioned under Coastal Structures the longshore current can transport people towards the (only just) submerged groynes, causing injury on impact.
- When the groynes are emerged from the water surface, any longshore current is deflected offshore along the upstream side of the groyne. Swimmers risk being caught in this current along the groyne. When the current along the groyne is invoked by a wave driven alongshore current and the tidal drive alongshore current acts in opposite direction, bathers can be transported hundreds of meters away from the beach. Therefore, the prevailing longshore current magnitudes and direction in combination with coastal structures should be included in the assessment of swimmer safety on a particular beach.
- A strong longshore current can create a potential dangerous situation by itself. Contrary to a beach with groynes, maximum longshore current velocities of up to 1.3 m/s were measured close to the waterline and in the alongshore troughs within the surf zone in considerable water depths (1.5 - 1.75m). Swimmers risk being transported alongshore at velocities greater than they can attain swimming. According to the lifeguards, swimmers try to swim against the alongshore current to get back to their reference on the beach. Therefore, the strong longshore current can cause a hazardous situation by itself.
- When a strong longshore current is combined with oblique troughs, hazardous situations for swimmers can occur.
- Furthermore, the longshore current plays an important role in the occurrence of rip currents on the open beach. This will be discussed hereafter. For now it suffices to say that when a dominant longshore directed current prevails along an open beach the risk on rip currents is very low. When the longshore current is weak and not in one dominant direction within the surf zone the risk on rips increases.

*Rip currents*

- This is an important aspect of swimmer safety and inter-related to the first three criteria (*bars,troughs and channels* / *coastal structures* / *longshore current*). Rip currents have a negative effect on swimmer safety because they are capable of transporting people (amongst others) away from the beach at greater speeds than bathers can attain swimming. Bathers generally try to swim back towards their point of reference on the beach (their towel or chair). But instead of getting closer to the beach, they are removed further. This causes panic, followed by exhaustion and is consequently very hazardous. GPS drifter measurements have shown that the extent of the rip currents on the open beach is often not much further than O (10 - 20 m) beyond the surf zone. And sometimes the drifters even re-entered the surf zone further downstream (transported longshore by the tidal current). This isn't realised by the general beach visitor. Thus, whether a rip extents far offshore or not, the part within the surf zone will generally cause the hazardous situation. Where and when rip currents are to be expected on the open beach and on a beach with groynes will be discussed separately.

- <u>Rips and groynes</u>
  The analysis of the lifeguard rescue reports revealed most rescues were performed at emerged groynes, forced by any longshore current (either by wave breaking or tidal driven). Measurements revealed velocities in these rips are generally twice the magnitude of the upstream average longshore current velocity. Maximum rip current velocities of 0.7 m/s were observed. Combined with the deep channels alongside of the groynes, these rip currents are very hazardous to swimmers. These rip currents become stronger with increasing wave or tidal driven alongshore current velocities. The offshore extent depends the tidal current direction. When the tidal and wave driven longshore current act in opposite directions, swimmers caught in the rip along the groyne, invoked by the wave driven current, can be transported hundreds of meters away from the beach. If the tidal and wave driven current act in the same direction the rip current is deflected around the groyne in the direction of the tidal current. In this case bathers stay closer to the beach drifting in alongshore direction. The offshore extent of these rips was observed to be between the tip of the groyne and 50 m beyond it.

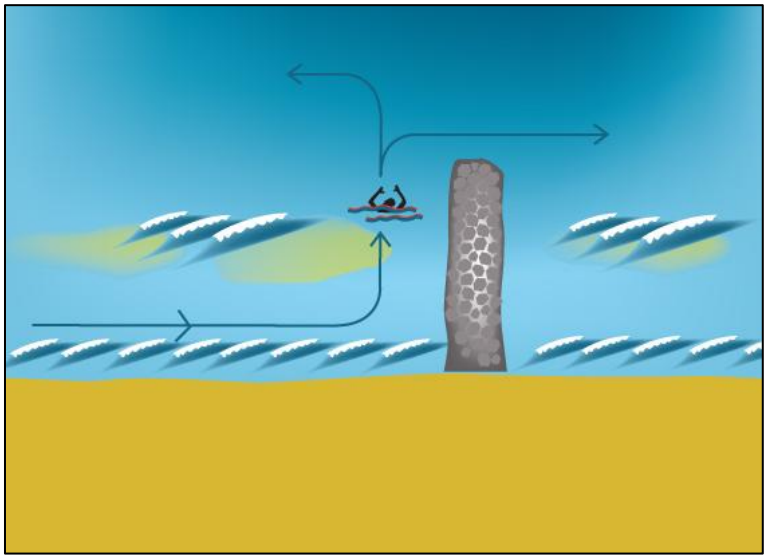


**Figure 5.2:** Any longshore current causes rips near groynes. When wave and tidal driven current work in opposite direction, bathers are transported furthest away from the beach. For coinciding current direcions bathers stay closer, though still beyond the breaker zone.

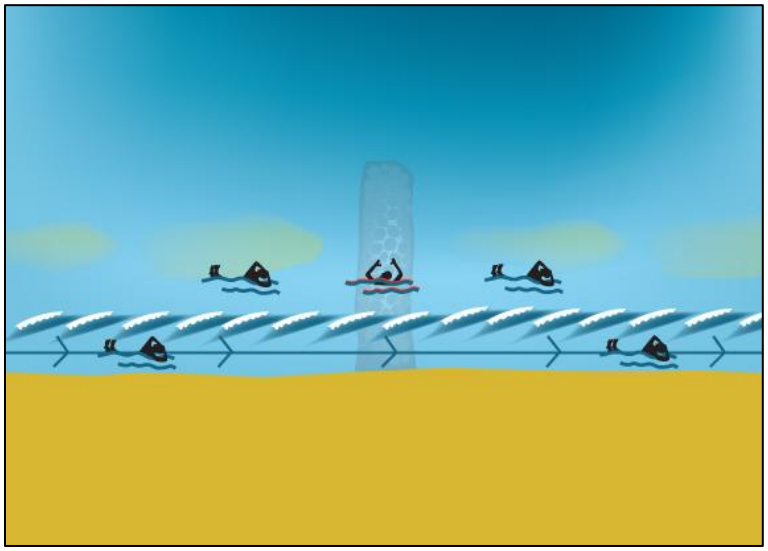


**Figure 5.3:** Only just submerged groynes combined with a longshore current can cause injury to bathers on impact with the stones.

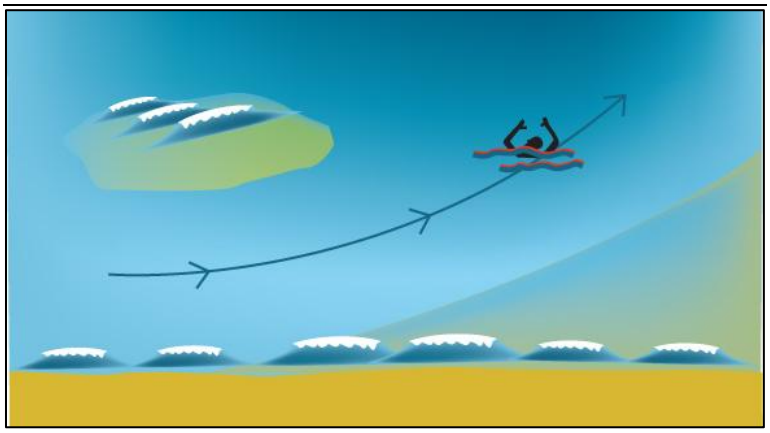


**Figure 5.4:** Oblique trough and longshore current can cause a hazardous situation for swimmers.

- Rips on open beach
  Along the open beach, rip currents were only observed during nearly shore normal incident, longer period waves and mild (offshore) wind conditions at locations within the surf zone where vertical variations in bottom topography were present. Under these circumstances long- and cross shore current velocities were in the same order of magnitude. No dominant longshore current direction was observed within the surf zone; the variations in the bottom topography within the surf zone control wave breaking, and consequently the current pattern. On the breaker bars only onshore directed current velocities were observed. In the deeper (rip) channels offshore directed velocities were observed. In the troughs within the surf zone, the longshore current was directed both in south and northward alongshore direction sometimes with a considerable offshore component associated with the feeder currents of a rip current.
  The rips on the open nourished rips were weaker than the rips near emerged groynes. The maximum rip current velocity O(0.45 m/s) observed on the open beach was orientated obliquely offshore in a pronounced slightly offshore directed trough, cutting through a breaker bar. Straight offshore rips were also observed, generally in less pronounced deeper areas within the surf zone. These were generally weaker than the oblique rips.

*Predictability*

- The lifeguards clearly expressed their concerns regarding the unpredictable occurrence (in location, orientation and moment of occurrence) of the rips currents on the open beach in comparison to the occurrence of rip currents on the groyned beach. Although the rip currents on the open beach were observed to be weaker and less frequent than the rip currents along the groyned beach, it is this unpredictability which concerns the lifeguards the most. This is for one part caused by their unfamiliarity with the rip currents on the open beach, and for the other part by the actual occurrence of the rip currents.
- On a groyned beach, the direction of the rip was always parallel to the groyne. At the tip of the groyne, the rip bends in the same direction the tidal current is acting. Thus when aware of the wave and tidal driven current direction, adequate rescues could be performed. The occurrence of the rip was also quite well known: when the groynes were emerged and a longshore current prevailed. Consequently, lifeguards would watch the area near groynes and in some cases act preventive by closing the immediate surroundings of the groynes for swimming.
- On the open beach surf zone morphology is dynamic (compared to the static situation near groynes). The rip currents appear and disappear at different locations along the beach. Sometimes straight offshore directed, other times obliquely offshore directed. Because of the unpredictability of the rips and unfamiliarity of the lifeguards with these kind of rips dangerous situations are spotted later, which is unbeneficial for the rescue. It also forces the lifeguards in a regressive role, because they don't know beforehand where a rip will form. Moreover, when a rip current incident is at hand, the unpredictability of the direction of the rip current complicates the rescue even more.

*Profile gradients*

- Steep or sudden changes in profile gradients have a negative on swimmer safety.
- Scarps on the high water berm (often observed post nourishment) block the view of the lifeguards on the waterline.
- Bathers can fall of the scarp, injuring themselves.
- A steep intertidal profile at the foot of the scarp can cause short powerful surf at high tide. The bathers can get knocked down by the surf, misinterpret the profile under water and consequently end up in short strong surf (or behind it), without being able to touch the bed. This is particular dangerous for elderly people or young children, see Figure 5.5.
- Sudden changes in the sub aqueous profile can also be dangerous. For instance when a submerged shallow bar is separated from the dry beach by only a narrow deep trough. This was observed a few months post nourishment. People running into the sea think they can dive into the water. Instead they risk diving straight into the bar which can cause serious injury.

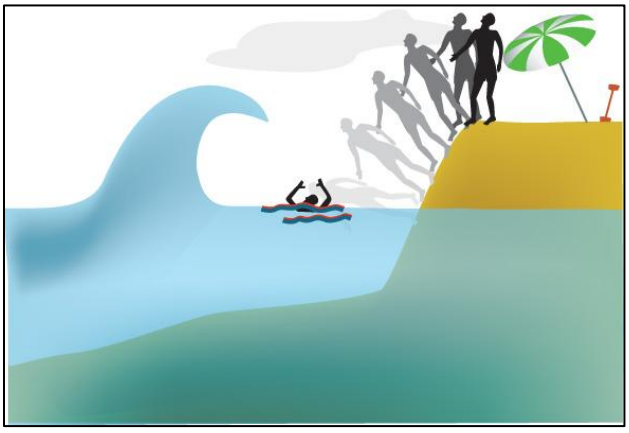


**Figure 5.5:** Scarps, steep slopes and surf can cause hazardous situations for bathers.

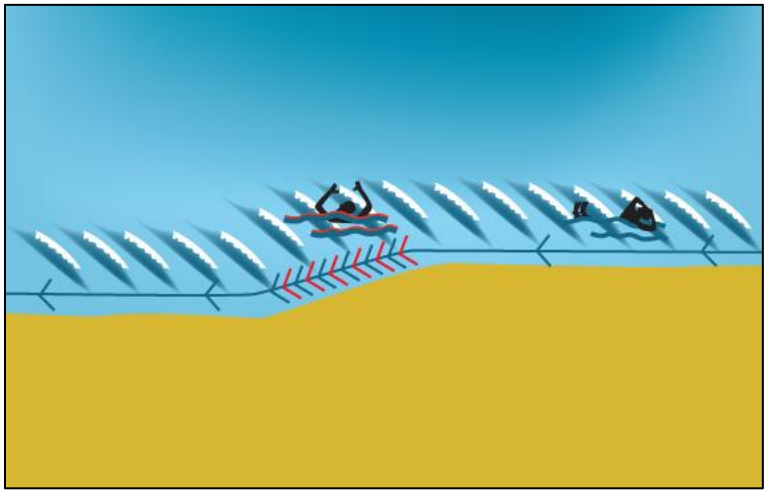


**Figure 5.6:** Acceleration in longshore current due to increasing wave angle of incidence with coastline.

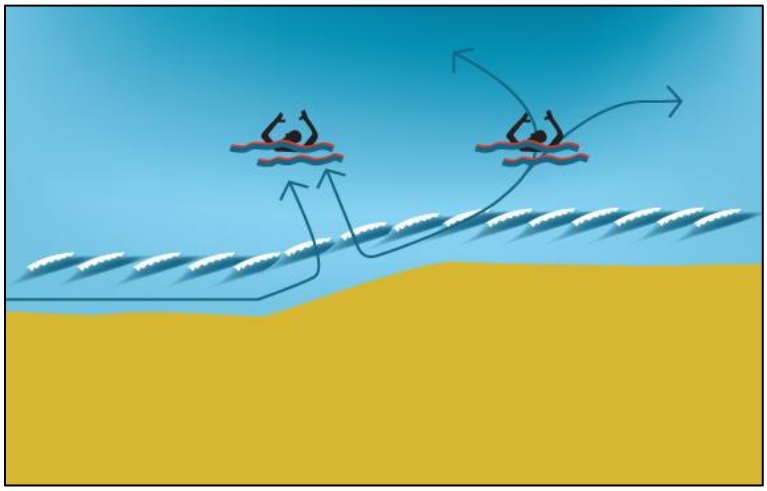


**Figure 5.7:** Near-normally incident waves on a gradient in the coastline have caused rips in the past.

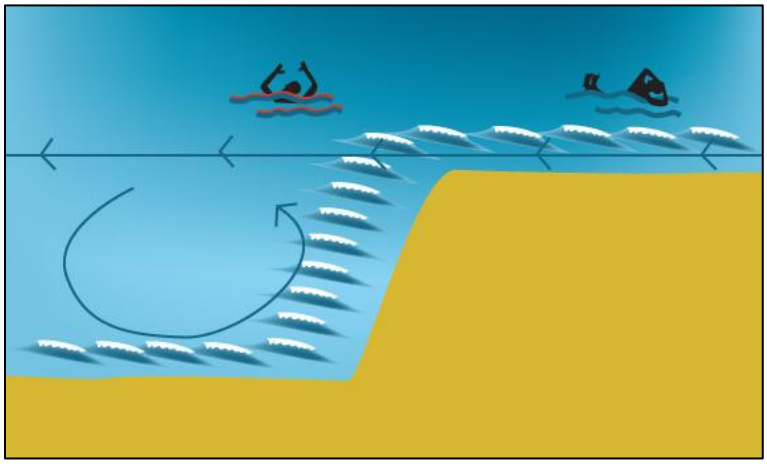


**Figure 5.8:** Very large gradients in the coastline could cause swimmers to end up far from the beach in any direction, due to flow seperatation.

*Alongshore coastline gradients*

- Alongshore gradients in the coastline affect the wave driven current. When the angle of the coastline with respect to the incident waves increases, the current will increase. Consequently, accelerations in longshore current are found along these gradients, Figure 5.6. When the wave angle with respect to the coastline becomes less, or in some cases even shore normal, rip currents could form as indicated by the rescue reports of the lifeguards, Figure 5.7.
- When the alongshore gradient is so strong that the alongshore current can't follow the coastline, the flow separates and vortex shedding can occur in the lee of the gradient. Eddies are formed in the lee side. Swimmers risk being transported towards the gradient with the alongshore current and consequently, (at the gradient) with the separated flow in the direction of the current alongshore (but now further away from the coastline), Figure 5.8.

## 5.2 Conceptual swimmer safety tool

The results of the analysis of the measurements, rescue reports and inventoried swimmer safety aspects in the survey amongst the lifeguards have been used to develop a conceptual swimmer safety tool. Based on visually observable parameters on the beach, the diagrams shown in Figure 5.10 and Figure 5.11 indicate whether rip currents are to be expected for a groyned or open beach. The parameters which are used in these diagrams are listed below and will be discussed first:

- Wave angle of incidence
- Tidal phase
- Vertical variations in bottom topography in the surf zone
- Bar depth
- Breaking wave height

*Wave angle of incidence*

The analysis of the measurements showed that the occurrence of rip currents on the open nourished beach is related to – and limited by- the longshore current within the surf zone. Besides wave height and wave period, the obliqueness of wave incidence with respect to the shoreline influences the generation of this current for an important part. The wave angle of incidence varies more over the measurements, than the wave height and wave period. An obvious difference in the character of the current pattern was revealed. Furthermore, the wave angle of incidence influences the longshore current but also water level gradients within the surf zone. Therefore, the wave angle of incidence is considered as a governing parameter in the occurrence of rips in relation to the longshore current. When waves break at an angle with respect to the coastline, they generate a current in the alongshore direction of wave propagation and a setup of the mean water level towards the beach in cross shore direction. The more oblique the waves break, the stronger the longshore current will be and the smaller the setup of the mean water level will be; a strong longshore orientated current pattern is created.

When waves break shore normal only a setup in mean water level is created behind the area of wave breaking towards the beach. Variation in wave breaker heights alongshore, either due to vertical variations in bottom topography within the surf zone or variations in incident wave breaker height, will consequently generate water level gradients. Current are generated towards areas of lower setup in water level: the feeder currents. These currents converge in areas of lowest water level setup, most often the deeper parts in the surf zone (where no wave are breaking), and form concentrated offshore directed currents: rip currents. As a consequence current directions and velocities within the surf zone will vary depending on locations along the beach in contrast to a dominant longshore orientated current pattern when waves are obliquely incident.

*Tidal phase*

The tidal phase determines the water level elevation and the direction and magnitude of the tidal current velocity. Most groynes along the Holland coast have crest levels around mean sea level. Consequently, the groynes are emerged in the low tide period and submerged in the high tide period. Along the South Holland coast, the flood tidal current is directed in alongshore NE direction and stronger O(0.5 m/s) than the ebb tidal current O(0.3 m/s). Depending on tidal phase, the alongshore current can act in both alongshore directions. A wave driven alongshore current in the surf zone can thus be directed in the opposite alongshore direction than the tidal driven current.

*Vertical variations in bottom topography*

The difference in bottom elevation between a breaker bar, trough and rip channel and the water level surface elevation causes different water depths in the nearshore. Combined with waves, these variations in bottom elevation cause variations in wave breaking. **Variation in wave breaking in alongshore direction** can generate rip currents, as discussed throughout this thesis. A beach with an alongshore trough and bar incised with a rip channel is shown in Figure 5.9. If waves break on the bar and not in the channel, alongshore variations in wave breaking occurs and consequently rip currents are generated (left panel, Figure 5.9). When waves are smaller or water levels are higher, waves propagate over the bars only to break on the (much more uniform) shoreline, no rips are formed (right panel, Figure 5.9). When waves are so large or variation in bottom topography small, waves will start breaking in the channel as well. This will limit the generation of rip currents.

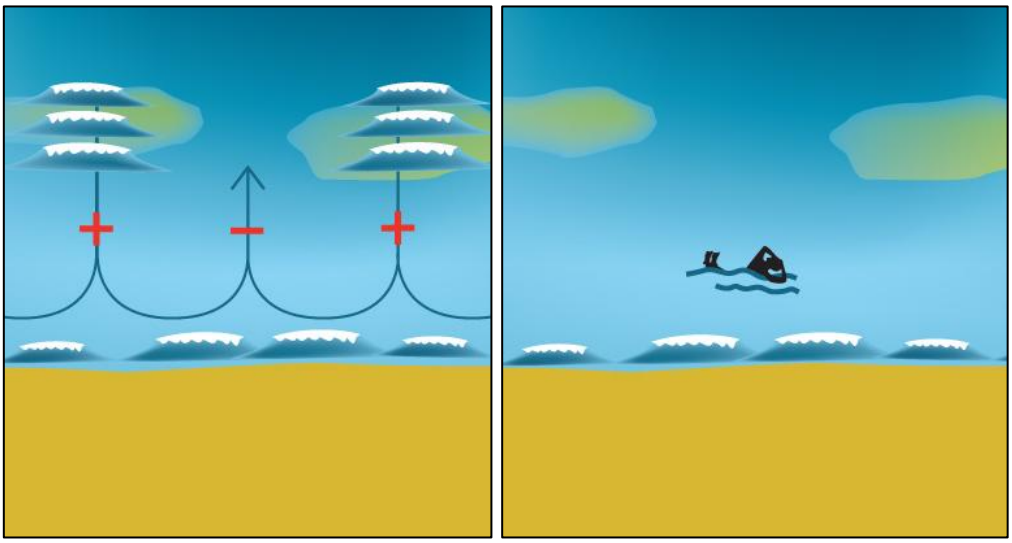


**Figure 5.9: Left** Alongshore variation in wave breaking due to bottom variations of the bar trough beach system causing rips. **Right:** Waves propagating over the bars, breaking on the much more uniform shoreline, causing no rips.

*Bar depth*
The difference of the bar crest elevation and the water level surface elevation gives the water depth on top of the bar in the beach profile. Combined with wave breaking criteria and breaker height, this parameter determines whether waves break on the bar or further onshore. For the situation shown in the right panel of Figure 5.9, this would mean no variation in wave breaking and consequently no rip currents.

*Breaking wave height*
Wave breaking was already mentioned in combination with the other parameters. The wave breaker height influences many things. When waves break oblique, increasing wave height increases the longshore current velocity. For the generally gentle sloping beaches along the Dutch coast, the surf zone width increases with increasing wave height. Water level set up due to wave breaking increase with increasing wave height. However, for ever increasing wave height, variations in wave breaking due to (the generally small) bottom variations along the Dutch coast will come to a maximum if waves break from far offshore towards the waterline. Water level gradients could be too small to generate rips for these condition. Rips could disappear and the mechanism of undertow could now satisfy mass balance (see section 2.3)

The diagrams shown in Figure 5.10 and 5.11 are developed with the idea that lifeguards on the beach can estimate the risk on rips, based on visually observable above mentioned parameters when looking at the sea. Combining these readily assessable parameters with the diagrams could be a tool for lifeguards to get a grip on the expected occurrence of rip currents on the groyned beach but especially on their new beach configuration.

*Groyned beach*
The diagram shown Figure 5.10 is designed for use on a groyned beach as encountered along the Dutch coast and based on the situation in Scheveningen before the nourishment was executed. It consists of half a circle with a groyne bisecting it. The groyne also represents the shore normal. During low tide the groyne is emerged (solid black bar). With rising tidal level the groyne slowly submerges, indicated by the dashed (mid tide) and dotted (high tide) groyne.
Three radial bands are drawn. The bands correspond to tidal water level elevation. The innermost band corresponds to high water, the middle band to mid tide and the outermost band to low water. The direction of the wave angle of incidence is drawn from the edge of the diagram towards the origin. The arrow representing the wave angle of incidence indicates the expected risk on rip currents as indicated in the diagram.

On a groyned beach, the entire low water period will be potentially dangerous due to any longshore current or wave breaking in between the groynes, invoking rip currents in the deeper channels near the groynes (red outer most band). N.B. a water depth of a few decimetres on the bars in between the groynes is required. When the longshore current is stronger due to more oblique wave incidence the risk on rips is relatively higher than for less oblique waves. The experiments of the 26$^{th}$ of January, 9$^{th}$ of February and 16$^{th}$ of July lie in this region. With water levels rising above mid tide (groynes submerging), the risk on rips diminishes or vanishes completely. If pronounced breaker bars are present within the surf zone and between the groynes, it is hypothesized that rips can still be observed in

the channels next to the submerged groynes for shore normal wave angles. However no proof hereof was obtained in this thesis. With increasing wave angles, the longshore current will flow over the groynes and the risk on rips will disappear. For high tide, no rips are expected, hence the green coloured area.

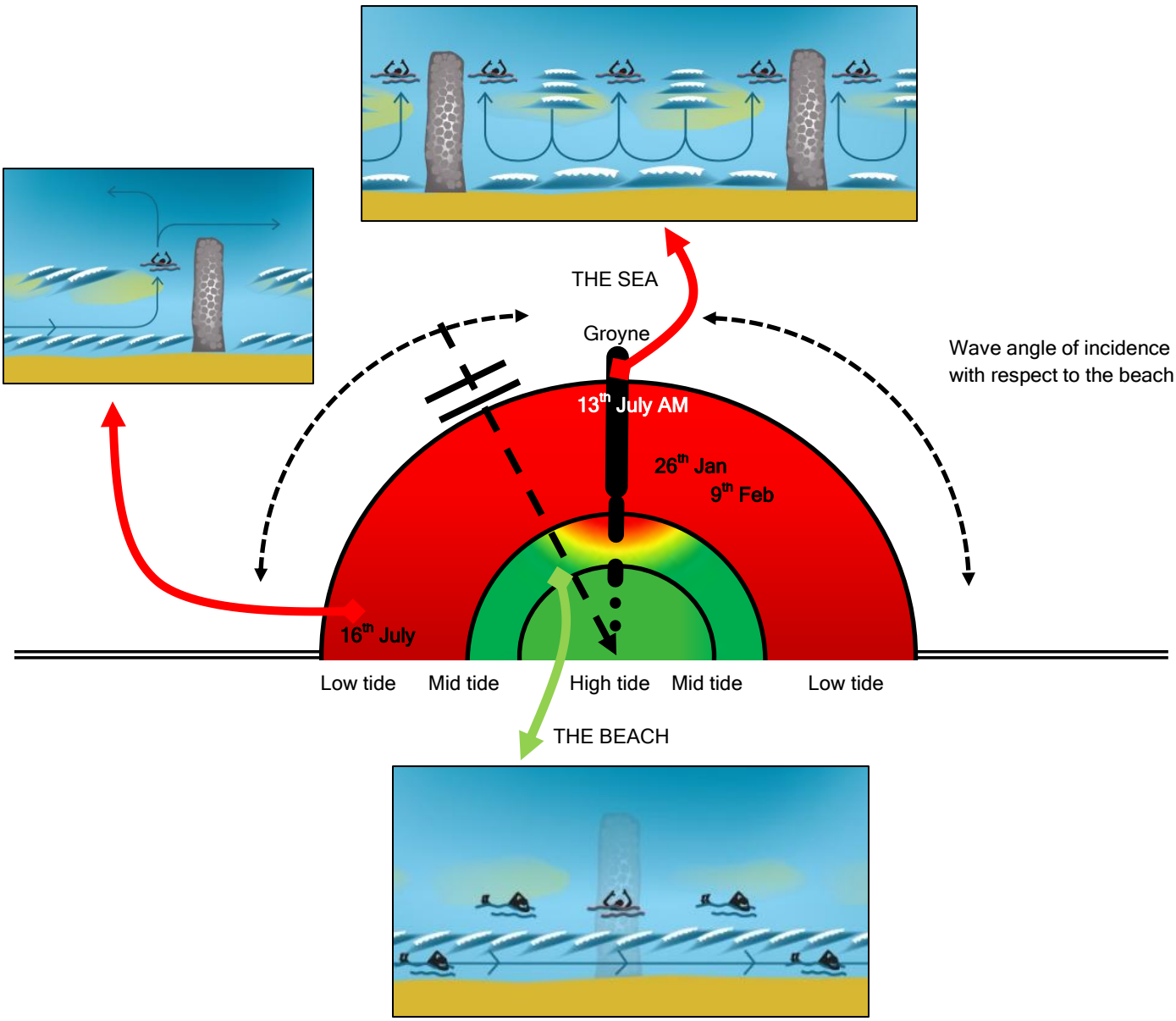



**Figure 5.10:** Rip current risk diagram for groyned beach based on wave angle of incidence with respect to the beach and tidal phase. Red-yellow-green shading indicates high-low-negligible risk on rip currents. Dates in diatram relate to current observations in Chapter 4. Character of current pattern indicated per region in diagram.

*Open beach*

The diagram in Figure 5.11 is designed for use on an open bar trough beach with rip channels as encountered along the Dutch coast and based on the situation in Scheveningen after the nourishment was executed. Naturally it can be used (if necessary adjusted) for any open beach with similar characteristics and prevailing conditions.

The diagram works in the same way as for the groyned beach. However, the radial bands are not directly related to the tidal water level elevation and represent more than one parameter. Vertical bottom variations, water level and breaking wave height are condensed into a more easily assessable parameter: alongshore variation in wave breaking. It is easy to assess whether significant wave breaking occurs or not. Negligible surf is represented by the innermost band. A shore break or surf zone full of white water due to irregular wave breaking and/or small bottom variations compared to wave breaker height would indicate few or no variation in wave breaking in alongshore direction to generate rips. This is represented by the middle band. A surf zone with areas of wave breaking on a (detached) breaker bar, interrupted by areas of less or no wave breaking would indicate variation in wave breaking in alongshore direction to generate rips. This is represented by the outermost band.

Lifeguards can assess approximate wave angles of the approaching and breaking waves. They can observe whether short shore break-like wave breaking occurs. Or they observe waves breaking consistently on a detached bar behind a trough, which they observed at low tide. They can also observe whether the entire surf zone looks the same or variation in wave breaking and calmer areas exists. Which also indicates vertical variations in bottom topography.

For the open beach the highest risk on rips is indicated for nearly shore normal incident waves in combination alongshore variations of wave breaking (outermost band). The bottom variations present within the surf zone influence wave breaking and consequently the current pattern. The combination of shore normal wave incidence and alongshore variations in wave breaking results in a high rip current risk. Moreover, for small wave angles, the longshore current will be small, allowing rips to form. The July 13$^{th}$ AM experiment lies in this region.

For the same wave angles but hardly any bottom variations within the surf zone (due to smaller waves or the same wave height in combination with higher water levels), waves will break close to the waterline without significant alongshore variations. The consequent short surf zone or shore break results in a low risk on rip currents to none at all. This is indicated by the greener areas towards de origin around the shore normal incident angles. The July 13$^{th}$ PM measurements fit this region.

For bigger wave angles the longshore current will increase quite drastically on the open beach. When at these angles due to the combination of waves, water level, bar depths and bottom variations there is still a variation in wave breaker height the risk on rip currents diminishes due to the stronger longshore current. Though oblique rips can form as indicated by the yellow area in the outermost band. The April 16$^{th}$ AM experiment is illustrative for this region.

For higher water levels and the same wave height, the surf zone edge will move onshore. The surf zone will be short (SS) and lack bottom variations within it. Combined with the generated longshore current, rips aren't likely to form indicated by the green area in the middle and innermost band. The experiment of April 16th PM along the steep slope of the gradient in the nourishment during high tide is an example of the current pattern in this regime. When wave angles increase even further, the longshore current will increase. Rips aren't likely to form at all, even when a wide surf zone with alongshore variations in wave breaking is observed. The July 16$^{th}$ experiment on the open beach is an example hereof.

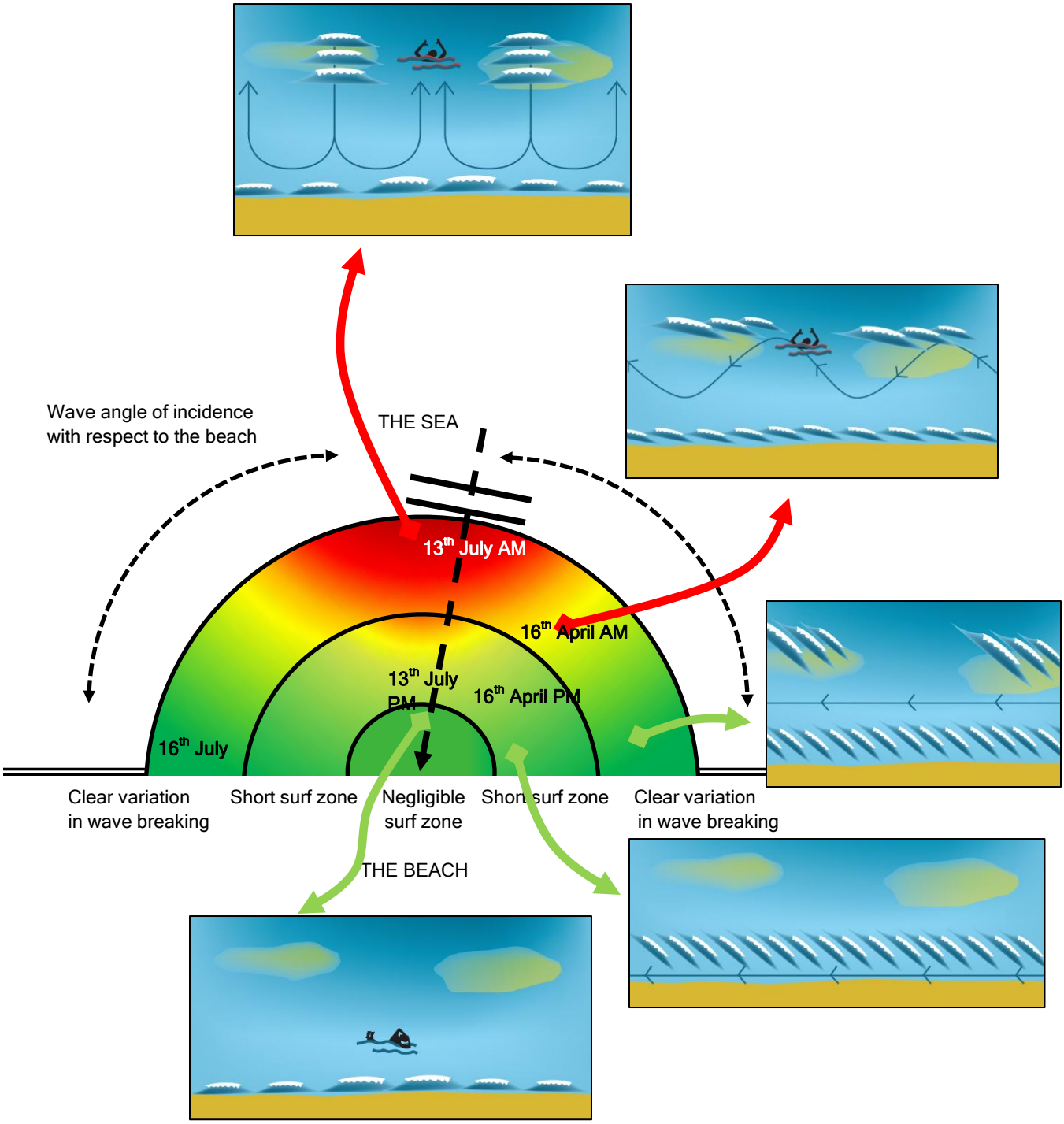



**Figure 5.11:** Rip current risk diagram for open coast bar trough beach with rip channels; based on alongshore variation in wave breaking and, wave angle of incidence with respect to the beach. Red-yellow-green shading indicates high-low-negligible risk on rip currents. Dates in diatram relate to current observations in Chapter 4. Character of current pattern indicated per region in diagram.

### 5.3 Conceptual coastal engineering rip current model

The conceptual swimmer safety tool presented here above is aimed at use by lifeguards. Another conceptual diagram is presented for broader coastal engineering applications and studies. Governing parameters are the same:

- Wave angle of incidence
- Tidal phase
- Vertical variations in bottom topography within the surf zone
- Bar depth
- Breaking wave height

The diagram applies to a bar-trough beach as found along the wind sea dominated Dutch coast, schematically indicated by Figure 5.12.

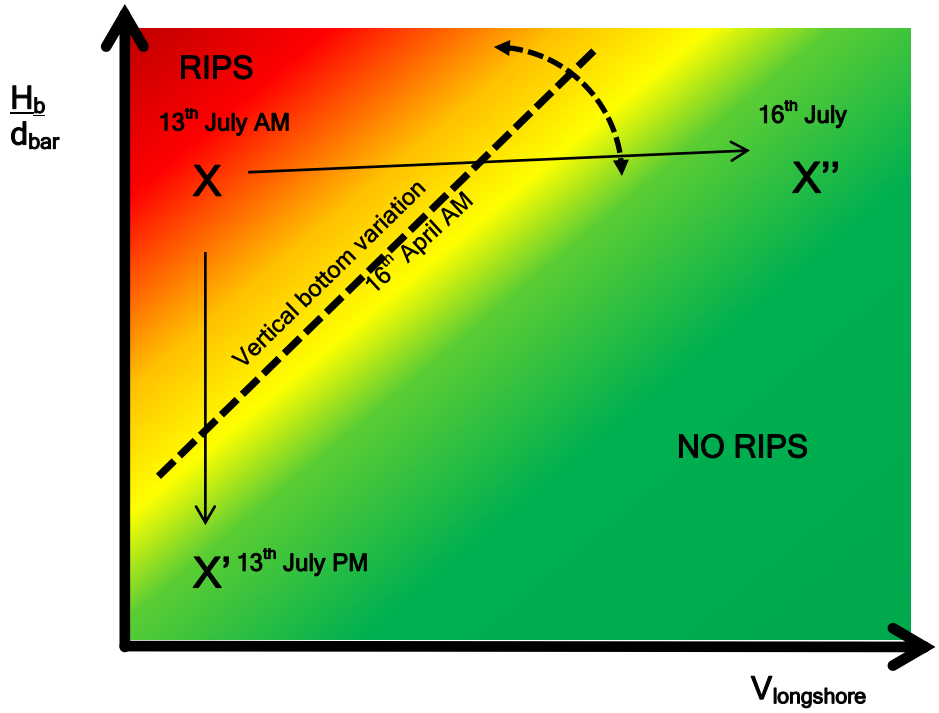



**Figure 5.12:** Conceptual coastal engineering rip model based on Longshore current velocity (V), Wave height over average water depth on breaker bar ($H_b/d_{bar}$) and vertical bottom variations within the surf zone.

The horizontal axis is the alongshore current velocity magnitude. It is influenced by the wave driven current (wave angle of incidence, wave height, bottom slope), wind driven current (wind strength, -direction and water depth) and tidal current.

The vertical axis is a parameter which reveals the ratio of incident wave breaker height ($H_b$) over water depth on top of a representative breaker bar ($d_{bar}$) and is consequently related to water level elevation and bottom topography. Moreover through breaker criteria it is also related to wave height, - period and beach slope. When this ratio ($H_b/d_{bar}$) is in the order of 0.8 or larger, it ensures wave breaking on the bar. When vertical variation are present, no wave breaking will occur in the channel; variations in wave breaking are introduced and rips can be generated. When it is significantly smaller than 0.8 waves propagate over the bar without breaking and break at the waterline, which results in less to no variation in wave breaking and hence generation of rips.

So when $H_b/d_{bar}$ is large and the longshore current in small this has proven to result in rips (Scheveningen 13th July AM measurements, Figure 4.9). The X in Figure 5.12 indicates that these conditions fall in the rip current regime.

For the same longshore current velocity and wave conditions, but higher water level elevation and thus a lower value of $H_b/d_{bar}$, the situation will shift across the dotted line to the regime were no rips are observed, as indicated by X' in the green area. The 13th July PM measurements fit in this area (Figure 4.10).

For bigger ratio $H_b/d_{bar}$, and for stronger longshore currents, the X will shift from the rip regime towards the green area, as indicated by X'', were no rips are observed due to the dominant longshore current. The July 16th measurements fit in this area (Figure 4.11 and 4.12).

The area of the April 16th AM measurement is indicated in Figure 5.3. The longshore current velocity magnitude was weaker than for the 16th of July, the breaker bar was less developed. Consequently, $H_b/d_{bar}$ was somewhat smaller combined with smaller variations in bottom topography, occasional weak oblique rip currents were observed (Figure 4.6).

The difference in channel depth (or trough depth) and breaker bar crest elevation was taken a measure for the vertical variation within the surf zone. Rip channel spacing, and the ratio of bar width over channel width also influence the occurrence of rips. The dotted line in Figure 5.12 represents (qualitatively) the transition between the regime where rip currents occur and the regime where the longshore current becomes too strong in relation to the rip currents. This transition zone is believed to be dependent on the amount or magnitude of the vertical variations within the surf zone. These vertical variations vary for different field sites along the Dutch coast. The diagonal line in Figure 5.12 is therefore flexible for different field sites. Along the North Holland coast (an accreting coast) vertical bottom variations are bigger than along the South Holland beaches. Consequently the occurrence of rip currents is different. For instance, when longshore currents are stronger, but also bottom variations are bigger, bars, troughs and rip channels are very pronounced, the same $H_b/d_{bar}$ parameter could still result in occurrence of rip currents. Consequently the dotted line tilts clock wise and shifts down in Figure 5.12. For beaches with less bottom variation than Scheveningen the line would tilt counter clockwise and shift up.

The concept can be further investigated by analysing datasets obtained at Vlugtenburg (REDNEX 2008-2009-2010) and Egmond (SEAREX2011) to determine critical bottom variation parameter, water levels and wave parameter.

# 6 Conclusions and recommendations

## 6.1 Conclusions

Commonly swimmer safety is associated with rip currents. On swell dominated coasts with large bathymetric variations in the nearshore and small longshore currents O(0.2 m/s) these rips can form a great risk for bathers. However, along the wind sea dominated Dutch coast with small vertical variations in bottom topography, frequent nourishments and combined tidal, wind and wave driven alongshore currents reaching 1 m/s or more, rips are found to be only one part of beach safety.

In a synthesis of the analysis results of detailed lagrangian current measurements, statistical data analysis of the rescue reports and inventoried swimmer safety aspects in the survey amongst the lifeguards, seven aspects of nearshore currents and beach configuration were formulated, which need to be evaluated in order to make a comprehensive assessment of the impact of nearshore currents and beach configuration on swimmer safety at a certain location:

- Bars, troughs and channels
- Coastal structures
- Longshore currents
- Rip currents
- Predictability
- Profile gradients
- Alongshore coastline gradients

Bather behaviour plays an important role in the evolution of a hazardous situation. Panic, physical ability, exhaustion, unfamiliarity with the sea or local situation all affect the course of a potentially hazardous situation.

General attainable swimmer speeds range for 0.2 to over 1.1 m/s depending on age, gender, and physical ability, based on tests performed in swimming pools. However, because of the above mentioned role of bather behaviour, current velocities greater than 0.25 m/s combined with water depths greater than chest deep are considered as potentially hazardous. Currents with an offshore directed component increase the risk on a hazardous situation for bathers.

Analysis of the rescue reports revealed that:

- the majority of rescues on the groyned beaches were performed in the low tide period, during side shore winds (SW and NE) of moderate strength (3-5 Bft) and oblique onshore winds of greater strength (4-6 Bft) with a large alongshore component (W and N). These conditions invoked strong rip currents along the sides of the emerged groynes
- rip current related rescues on the open nourished beach were performed during near-normally incident longer period waves and mild (offshore) wind conditions, indicating that swell type wave conditions (for Dutch standards) are responsible for the occurrence of rip currents on the open nourished beach
- in general most rescues are performed during the low water period
- wave conditions during rescues were most energetic for rescues performed with SW and W wind on the groyned beach.
- air temperature varied between 15 to 34 °C, though most temperatures at times of the rescue are between 19 to 25 °C

However, no distinct causal relation between swimmer safety and hydro meteo conditions could be established, based on the performed analysis and available data. There are some combinations of hydro meteo conditions and locations that have caused more rescues than others. This is mainly due to the fact that some conditions prevail more often than others, resulting in a higher rescue count for these conditions. But partly also due to the combination of these conditions with the beach configuration and the associated presence of rip currents caused by these conditions. Side shore orientated conditions and low tide caused many rescues in rips near groynes. For the same conditions no (rip current related) rescues where performed on the open nourished beach. Conditions that did cause rescues on the open beach, where strongly onshore orientated: longer period near-normally incident waves and mild (offshore) wind conditions. These conditions also caused rescues on the beaches with groynes. But, as for all conditions that caused rescues, not all occurrences of these conditions caused rescues. This leaves a causal relation between hydro meteo conditions and swimmer safety hard to establish.

*Rip currents near groynes*

Detailed lagrangian current measurements performed on the groyned and nourished beach confirmed the existence of rip currents near emerged groynes and harbour jetties. They were observed in all experiments and therefore assumed to be permanently present next to these structures (when emerged) due to any longshore current or wave breaking in between these structures. Velocities in these rip currents were generally twice the magnitude of the average alongshore wave driven current O (0.4 m/s). The maximum measured rip current velocity was 0.7 m/s. When the wave and tidal driven current act in opposite alongshore direction, the offshore extent of the rip

current originating next to these structures can be as far as several hundred meters. This is very hazardous for bathers. When the wave and tidal driven current act in the same alongshore direction, the extent of the rip current originating next to these structures, is limited to the tip (contour) of the structures or O(50 m).

*Rip currents on the open beach*
On the open beach rip currents were observed when:

- the alongshore current velocities were weak O(<0.20 m/s)
- longer period waves were near-normally incident
- mild (offshore) wind conditions prevailed
- vertical variations in bottom topography were present within the surf zone, causing alongshore variations in wave breaking.

Under these circumstances long- and cross shore current velocities were of the same order of magnitude. No dominant longshore current direction was observed within the surf zone. The current pattern is topographically controlled; the variations in the bottom topography within the surf zone control wave breaking, and consequently the current pattern. On the breaker bars only onshore directed current velocities were observed O(0.30 m/s). In the deeper (rip) channels offshore directed velocities were observed O(0.25 m/s). In the troughs within the surf zone, the longshore current was directed both in south and northward alongshore direction sometimes with a considerable offshore component associated with the feeder currents (O(0.45 m/s)) of a rip current.
The direction of the rip currents on the open beach varied between 45° to 90° offshore. The oblique rips were stronger than the straight offshore directed rips; O(0.45 m/s) and O(0.25 m/s) respectively. The oblique rip was related to a strong feeder current in an oblique trough. The offshore extent O(>100 m) was quite large. The extent of the straight offshore directed rip was smaller O(10 m) beyond the edge of the surf zone.

*No rip currents on the open beach*
No rip currents were observed along the open beach when oblique waves and wind prevailed. For these conditions the current pattern within the surf zone is dominated by a strong longshore current in the direction of wave breaking, generated by the obliqueness of wave incidence (amongst others). For increasing oblique wave incidence, increasing longshore current and decreasing cross shore current velocities were observed. The longshore current velocities within the surf zone were observed to be at least three times as high as the cross shore velocities in the surf zone during the experiment with wave angles larger than 20°. Vertical variations in bottom topography within the surf zone only caused a weak onshore directed component in the otherwise dominantly longshore orientated current.

Neither were rip currents observed on the open beach when no vertical variations in bottom topography were present within the surf zone, either due to the morphology of the beach (lack of formation of breaker bar shortly after nourishment) or due to a combination of tidal level and incident wave height.

For slightly less oblique waves, angles between 10° to 20°, the current pattern within the surf zone was still dominantly longshore orientated, with an onshore component. However, the longshore current velocities were less strong (approximately twice as strong as the cross shore velocities). Occasionally very short oblique rips were observed within the surf zone.

*Longshore current on groyned and open nourished beach*
A big difference between the longshore current along a groyned and open beach is the location and magnitude of maximum current velocities. Maximum current velocities O(1.3 m/s) along the open beach were measured close to the beach face diminishing towards the end of the surf zone, with a second maximum O(0.5m/s) just on and offshore of the deepest part of the trough. This is contrary to the distribution of the longshore current along a beach with groynes, where maximum current velocities O(0.5 m/s) were observed towards the surf zone edge.

*Rip current regime*
The occurrence of rip currents on open beaches along the wind sea dominated South Holland coast was shown to be strongly related to and limited by the longshore current magnitude. Rip currents were observed when long- and cross shore current velocities were of the same order of magnitude, which was observed only for near-normally incident waves. No rip currents were observed when longshore current velocities were approximately three times higher than cross shore velocities, which was observerd for breaking wave angles of incidence larger than 10° to 15°. Wave angle of incidence, wave height, wave period, tidal level and vertical variations in bottom topography within the surf zone were identified as crucial factors in the occurrence of rip currents along the wind sea dominated Dutch coast.

Conceptual swimmer safety tools were presented for application by lifeguards on a groyned and open beach. Based on the above mentioned (and readily assessable) parameters the relative risk on rip currents can be estimated.

A second conceptual model was presented for coastal engineering purposes, in which the regime of the occurrence of rip currents along the Dutch coast can be evaluated in a quantitative way.

### 6.2 Recommendations Swimmer safety

*Causality through bayesian model approach*
No causal relation between swimmer safety and certain wave, wind and tidal conditions could be established in this research.
A causal relation between hydro meteo conditions and swimmer safety is hard to establish by comparing two to three parameters with each other. Based on the performed analysis on the available rescue data, it isn't possible to identify a true causal relation between the parameters and swimmer safety. Moreover, in the course of the analysis the importance of accurate rescue data became more apparent. For this small dataset, one single day with many rescues or unfiled reports on other days influence the distribution of rescues a lot. The next step in establishing a causal relation between hydro meteo conditions and swimmer safety is to include social parameters and start a daily monitoring campaign on:
1) Supply of possible swimmers:
- Amount of beach visitors and actual bathers
- Sort of beach visitors (tourist, locals)
- Listing public holidays or national events
- Beach events (type: e.g. Regatta, BeachVolley, Party)

2) Lifeguards:
- Preventive measures of lifeguards (why, where, when)
- Awareness of lifeguards
- Communication towards public
- Rescues (why, where, when, characteristics of victim)

3) Beach configuration
- Rip channels
- Coastal structures
- Gradients
- Sandbars/deep troughs

4) Hydrodynamics
- Wave conditions
- Nearshore currents

Off all variables listed above, distributions of occurrence throughout the year can be made. Combining these modules into a Bayesian model, the dependencies of the variables can be revealed. This would be the ultimate way to find out whether a causal relation between specific hydro meteo conditions and swimmer safety exists.

Through numerical modelling, the nearshore hydrodynamics are simulated based on data measurements offshore. However, these models have never been validated with nearshore wave, current and bathymetric data. Therefore it is recommended to perform wave, current and bottom topography measurements in the nearshore in front of the beach for which this causal relation is investigated. At Scheveningen this could be done by:
- An ADCP/ADV attached to the pier of Scheveningen
- ARGUS cameras on the lighthouse of Scheveningen
- Topography measurements of the nearshore with the TU Delft NeMo Jetski
- Surf zone GPS drifter measurements

The ARGUS images could also be used to help the rescue brigades in identifying the locations of bars, troughs and (rip) channels. This would take a part of the uncertainty and unpredictability away.

Another recommendations is to create lecture material for the rescue brigades regarding the different types of waves (wind sea – swell) and how they influence the generation of rip currents and current pattern in the nearshore in general.

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