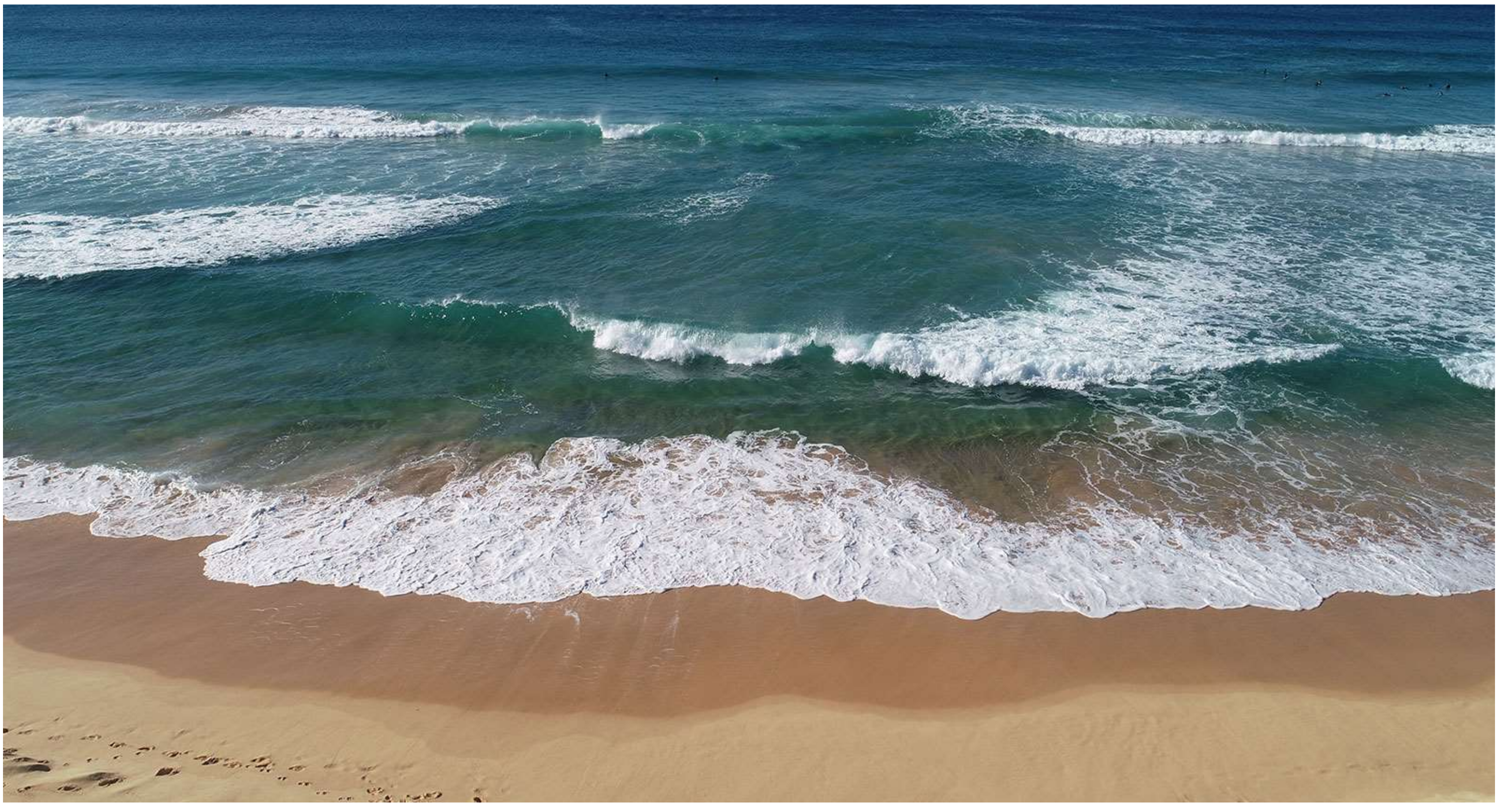

RIP CURRENT RELATED SWIMMER SAFETY

Abstract

Rip currents, nearshore seaward currents, are one of the main dangers in swimmer safety. Nevertheless, little is known about the key parameters causing these currents for sea-wind dominated coasts like here in the Netherlands. This research project will investigate these parameters to increase the knowledge based on rip current related rescues, so that the public awareness increases and lifeguards know when and where to be extra alert.

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24-05-2024, Final version

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During this whole period of research and writing my thesis about rip current related swimmer safety, a few people have been particularly important who I would like to thank.

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I would also like to thank Martin Hoogslag of the institute for safe swimming waters (NIVZ) for supplying us with the rescue data of The Hague, Monster and Egmond. Without your help it was not possible to do the research.

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Tom Luiks
Utrecht, 24-05-2024

Abstract

Rip currents form a significant challenge for beach safety. These nearshore seaward currents are often hard to spot and even harder to predict. Although several studies have been done on this topic, by far the most were conducted in countries with swell dominated coasts instead of wind-sea dominated coasts like in the Netherlands. Along the Dutch coast, every summer bathers get into trouble because of rip currents. Here, conditions (e.g. number of bathers and environmental parameters) differ along the coast and it is yet unknown under which conditions rip currents have the largest impact on swimmer safety. Therefore, the following research question is formulated: **Under what circumstances do rip currents pose the greatest threat for bathers along the Dutch coast?** The aim of this research is to find the link between rip current related rescues and environmental weather and water parameters along the Dutch coast. To answer this question, rescue data was obtained from three different sites (Egmond, The Hague and Monster) for the summer periods (May – September) of 2020 till 2023, in cooperation with the NIVZ, the Dutch institute for safe swimming waters. The data was then subdivided in three categories: rescues are either (1) certainly, (2) probably or (3) possibly related to rip currents. Subsequently, this research focussed on the category 1 rescues and linked these to the local parameters. The coupling included water data such as: wave height, wave angle, wave period and water height, but also weather data: wind angle, wind speed, temperature, rainfall, and sunshine. Extraordinary days with three or more rescues were compared with similar days in the dataset on basis of outstanding environmental parameters, to figure out what made these days so dangerous for bathers. The results revealed that determining the causal relationship between rip currents and rescues is challenging but a few parameters consistently stood out. Notably, waves always arrived at an oblique incident angle with water levels generally below mean sea level. The wind rarely blowed directly offshore and was on the high incident days always directed in the same direction as the waves. Between sites, Egmond predominantly showed rip current related rescues with waves from the south while The Hague and Monster showed more rescues with waves from the north. The differences in wind angle between sites were less clear. The study also underlines the role of weather parameters in rip current danger, highlighting the increased danger on dry, warm, and fully sunny days when beach attendance is the highest. For future research, a consistent registration system for rescues is recommended, making it easier to investigate specific causes of beach/sea related danger and harm. On a longer term, the application of artificial intelligence for an automated detection of rip currents from satellite or video footage is recommended. Moreover, to prevent people from getting into problems it is also proposed to further invest in creating awareness, such as through school programs, an app/site, commercials, citizen science and better information on location.

Table of content

1. Introduction

The Dutch beaches annually attract tens of millions of people, both tourists and locals. The most popular beach, Scheveningen, is visited by 15 to 20 million people on a yearly basis (*van der Zee & Klomp., 2020*). For all the beachgoers, no matter if they want to either relax, swim, or do water sports, their safety must be taken care of. In the Netherlands this is organized by each coastal municipality individually, but mainly conducted by two organisations. The KNRM, overseeing the Frisian islands: Vlieland, Terschelling, Ameland and Schiermonnikoog and the 'Reddingsbrigade', responsible for the mainland coast and Texel.

According to literature, currents are the main cause of severe injuries along coastlines, especially rip currents. Rip currents are narrow, strong seaward currents, moving through the surf zone (*Bowen, 1969*), caused by a combination of waves, longshore currents, and local bathymetry. With the right circumstances, rip currents can extend to more than three hundred metres away from the surf zone with velocities up to 0.6m/s (*Winter et al., 2014*). Despite the potential dangers posed by rip currents, studies from around the world reveal alarmingly low awareness among beachgoers. For instance, a survey in Australia (*Uebelhoer et al., 2022*) found out that 59,9% of the participants knew what a rip current was. When it came to identifying rip currents on six different pictures, 43,8% could only identify between zero and two pictures correctly. Another study conducted in New Zealand (*Pitman et al., 2021*) looked at the ability to identify rip currents in real life. Only a shocking 22% of the respondents was able to identify the in-situ rip current. Although there is no comparable research done in the Netherlands yet, each year people must be rescued from near shore rip currents. So, the knowledge of the regular beachgoers on the dangers and identification of rip currents is dangerously low and must be improved.

Besides just beachgoers, the overall knowledge about rip currents and especially their development in a wind-wave driven systems is low. Quite some research with the focus on rip currents is conducted around the world but most of them are about swell dominated coasts. This is different than the wind sea dominated coasts like in the Netherlands, characterized by a lower overall wave height and period. Still, as mentioned, also along the Dutch coast swimmers can get in dangerous, sometimes life-threatening situations and in the worst-case scenario drown because of rip currents. In 2022 for example, according to the NIVZ, six people drowned along the Dutch coast and according to number published by the Reddingsbrigade 323 swimmers were rescued from a life-threatening situation. The exact number of life-threatening situations caused by rip currents is unclear.

The aim of this research is to gain more knowledge about crucial parameters in rip current development and their danger for bathers. We will first take a step back and offer a general insight into currents along the (Dutch) coast in chapter 2. Chapter 3 outlines the methodology, starting with an examination of the Dutch rescue data to determine if the rescues were related to rip currents or not. This data is coupled to the local parameters like wind, waves, weather, and tide. The results are shown in Chapter 4 and finally, in Chapters 5 and 6, the findings of this work are discussed, and the main conclusions are given, respectively.

2. Background swimmer safety

Swimmer safety depends on a lot of different elements and differs per location and over time. This chapter zooms in on the various aspects determining swimmer safety and which of these aspects are the most important for the Netherlands. It will evaluate the importance of local parameters in the existence of dangerous currents and other, human related swimmer safety risks. In the end there is enough information to formulate a research question.

2.1. Nearshore currents

According to de Zeeuw (2011) there are seven aspects for nearshore currents determining swimmer safety around the world. It is all an interaction nearshore bar systems, currents, coastal structures, and environmental conditions. In real life situations the following aspects are often combined, increasing the complexity:

The combination of ***bars, troughs and channels*** is the first important aspect for swimmer safety. Pronounced differences in height increases the currents in the troughs, also increasing the risks for bathers. For example: shallow bars attract a lot of bathers during low tide, they are often not aware that these shallow bar systems have the maximum occurrence probability of **rip currents** (*Li et al., 2018*)(Figure 1a). These currents can extend 10 to 20 meters beyond the surf zone (zone where the waves break) (*Winter., 2014*). Due to the many factors in the emerging process, initiated by local bathymetry and breaking waves, these 'open beach' rip currents have a low **predictability** (*de Zeeuw., 2011*), highly increases the danger for bathers. When rip currents are not present in the bar system it can still be dangerous on a shallow bar because tides rise and, after a while, people cannot wade back like how they came. The surprise of the deep water in combination with possible other currents can cause panic and exhaustion and thereby be extremely dangerous (*de Zeeuw., 2011*).

Coastal structures like groynes and harbour jetties are not dangerous by themselves but they can be in combination with waves and alongshore currents. Bathers can be hit against the structures when emerged or get dragged over them when just submerged and thereby injure themselves. When groynes and jetties are (almost) emerged, longshore currents can also get deflected into *rip currents* which can take (injured) bathers further offshore (de Zeeuw., 2011)(Figure 1b). These boundary-controlled rip currents do have a higher predictability than open beach rip currents but can extend for several 100s of meters (*Scott, T. et al., 2016*). Despite the potential offshore reach, most of the danger is caused within the surf zone. Panicked swimmers become fatigued by trying to swim against the current, leading to exhaustion and eventually drowning (*Brander et al., 2011*).

A combination of wind, waves and tidal flow are responsible for another aspect: ***longshore currents***. These currents can be decelerated by groynes. But as mentioned above, the interaction between the two can also lead to the formation of rip currents due to deflection. The longshore current itself can be dangerous as well because bathers try to swim back to a reference point when they notice that they have been dragged alongshore. Because the swimming ability of bathers is often insufficient, they get exhausted quickly and panic when trying to swim against the current (de Zeeuw., 2011). Apart from just longshore current and rip currents, there is also a combination: rip currents with an oblique trough. This is not a flow in a ninety-degree seaward angle but slightly aimed towards the dominant longshore flow direction. In these oblique currents the flowrate is often higher than in straight offshore currents, but lower than the longshore current itself (*Winter et al., 2014*). Because of the velocity and slight seaward direction, the oblique currents are harder to recognise and more dangerous. Chapter 2.3 will elaborate on this in more detail.

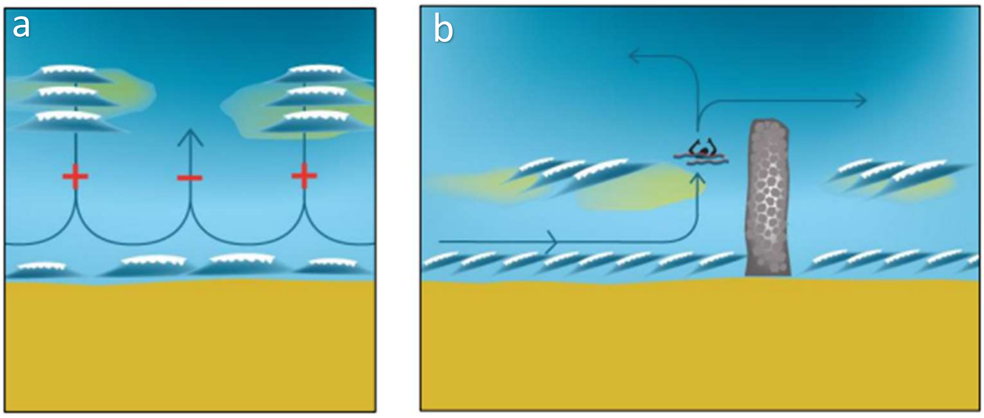

Figure 1 a & b - Two main types of rip currents, a: for open beach and b: boundary related (de Zeeuw., 2011)

In the local topographic situation ***profile gradients*** and ***alongshore coastline gradients*** are main aspects. Steep and sudden sub aqueous changes can surprise bather and cause panic, especially in turbid waters. Also, on-beach profile gradients can be risky in the form of scarps on high water berms. Bathers can fall and injure themselves and it blocks the view of lifeguards (de Zeeuw., 2011). If the steep scarp profile is intertidal, it can cause a powerful surf at high tide with the risk of bathers being swept out and having difficulties getting back on the beach. About the coastline gradients, the wave incidence with respect to the coast determines the strength of the longshore current. When this angle increases the longshore current will increase. When the angle decreases or even becomes shore normal open beach, rip currents can form which changes the whole situation (Figure 2a). When a longshore gradient is so strong that currents cannot follow a curved coastline, the flow separates, and vortex shedding can occur leading to a new danger for swimmers (Figure 2b).

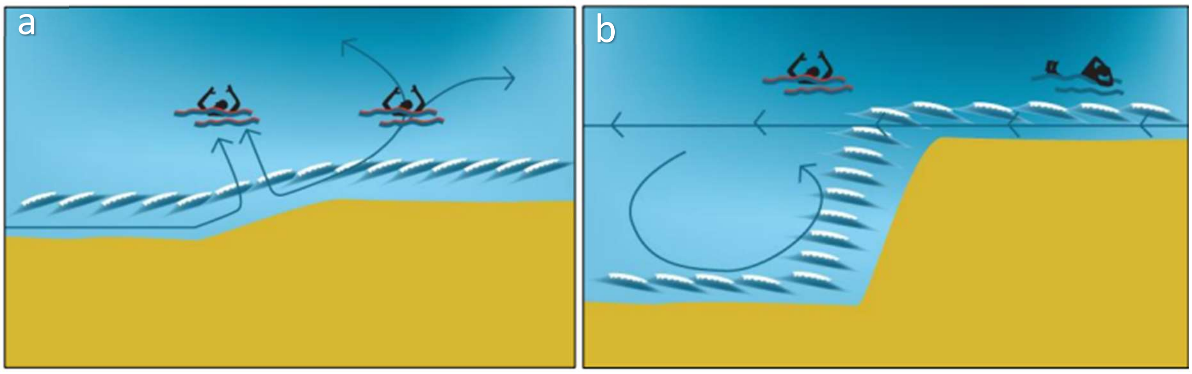

Figure 2 a & b - Dangers of strong alongshore coastline gradients, a: offshore flow and b: vortex flow (de Zeeuw., 2011)

2.2. Distinct types of rip currents

The similarity between all rip currents is that they are a potential danger for bathers and swimmers, but as already mentioned in Chapter 2.1 variations exist in the forcing. There are three types of rip forcing, resulting in six distinct types of rip currents (*Castelle et al., 2016*) (Figure 3). The rip forcing can be based on either hydrodynamics, bathymetrics, or boundaries. In real life the distinct types of forcing are often mixed making is very complex (Appendix A).

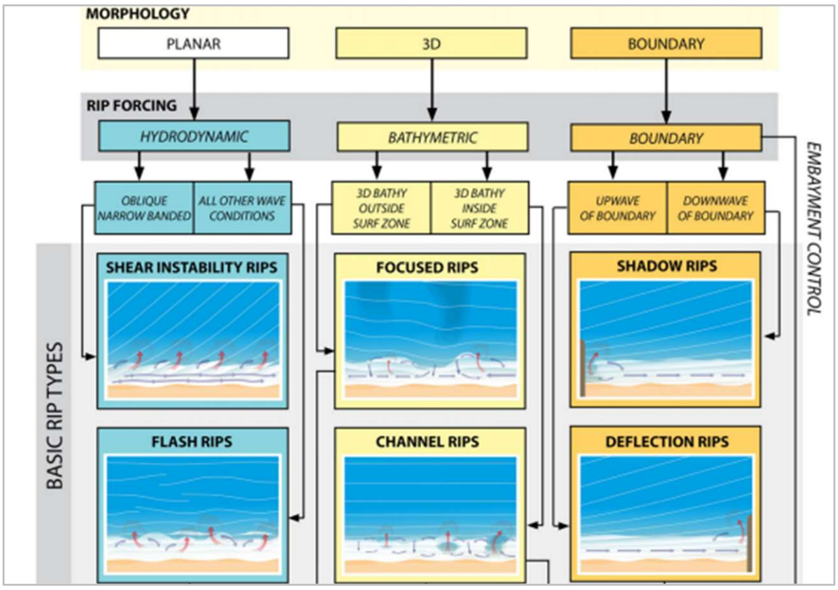

Figure 3 - The six distinct types of rip currents (Castelle et al., 2016)

<u>Hydrodynamic rips</u>, occurring at open beaches, are random in time and location, with time-averaged longshore currents near zero within the surf zone (*Spydell et al., 2007*). The key force-response relationship that drive purely hydrodynamic rips are complex and still poorly understood. There are two distinct types of hydrodynamic based rips, based on the wave conditions. With oblique narrow banded waves ***shear instability rips*** are formed, with all other wave conditions ***flash rips*** are formed (Figure 4) (Feddersen., 2014).

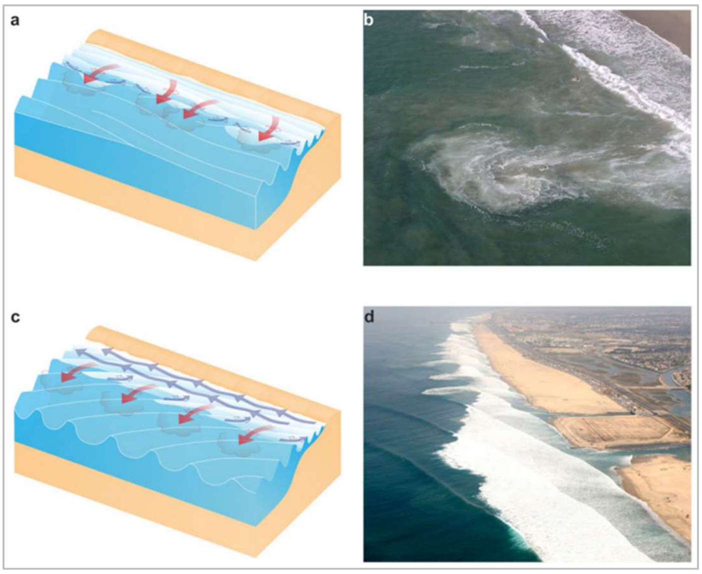

Figure 4 – The two variants of hydrodynamically forced rips, a & b represent the flash rips and c & d the shear instability rips (Castelle et al., 2016)

Bathymetrical rips are more well documented. Here the rip flow velocity increases with an increasing wave height, wave period and/or a decreasing water depth over a sandbar crest. Waves break over the bar and the resultant wave forcing causes a relatively high-water level set-up in the trough between the beach and the bar. In the channel the waves break later (due to the deeper water) and induce less set up. A longshore flow parallel to the beach is initiated (by a gradient in set-up) towards the rip channel where it is deflected offshore (*Dalrymple et al., 2011*). On sandy beaches, the maximum rip current activity tending to occur around low tide due to changing breaking wave patterns (*Scott et al., 2014*). The difference between the two types of bathymetrical rips is the 3D bathymetry. If there are big variations inside the surf zone ***channel rips*** are formed, if the bathymetrical variations are located outside the surf zone ***focussed rips*** are formed (Figure 5).

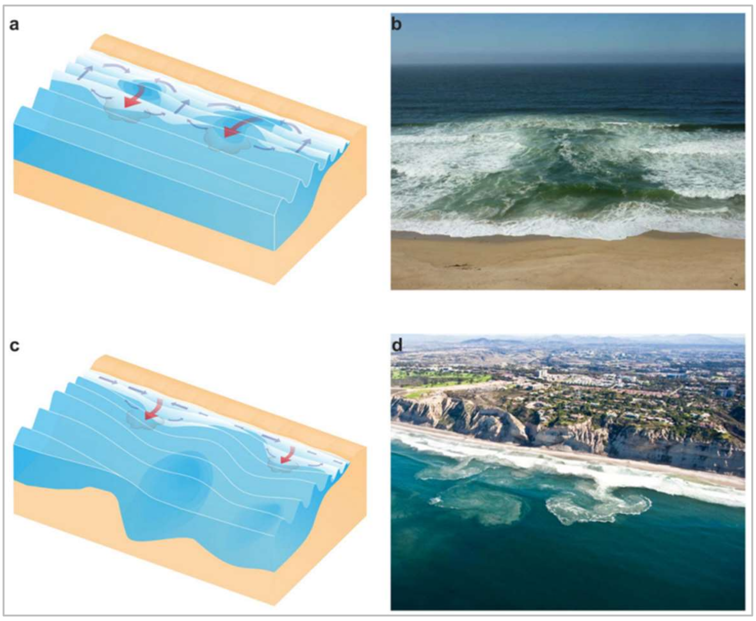

Figure 5 - The two variants of bathymetrically forcer rip currents, a & b represent the channel rips and c & d the focussed rips (Castelle et al., 2016)

Boundary controlled rips are, as the name implies, related to fixed boundaries like harbour jetties or groynes and the deflection of the longshore current on those. Wave height, wave direction, tidal flow and boundary geometry all play a key role in both rip current flow velocity and circulation regime of boundary currents (*Castelle et al., 2016*). whether the rip is formed down wave of the boundary or up wave of the boundary determines if it is either a ***shadow rip*** (down wave) or a ***deflection rip*** (up wave) (Figure 6). For shadow rips, the wave angle and boundary geometry are key factors (*Pattiaratchi et al., 2009*), shadow currents are often circulatory. For deflected boundary rips both breaking wave angle and wave height are the most important parameters. Deflection currents are not circulatory and can extent for multiple surf zone widths (*Scott et al., 2016*).

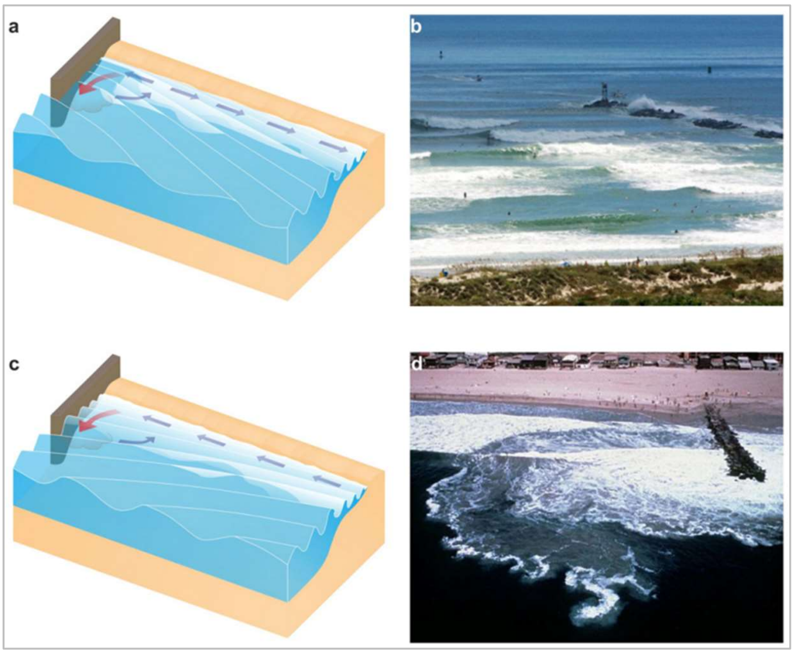

Figure 6 - The two variants of boundary-controlled rips, a & b represent the shadow rip and c & d the deflection rip (Castelle et al., 2016)

2.3. Rip currents along the Dutch coast

The Dutch coast is wind sea dominated, which means the waves are most often locally generated by the wind and therefore have a relatively short period. The amount of research for coastlines like this is scarce and mainly relies on the Dutch studies of de Zeeuw (2011) at Scheveningen and Winter (2014) at Egmond. Due to the wind-sea dominance most rip currents are generated by longshore currents in combination with coastal structures like groynes and harbour jetties, so boundary-controlled rips. This combination produces the strongest rip currents, up to 0.7m/s with a peak activity during mid/low tide when the groynes are emerged, according to research in Egmond (*Winter et al., 2012*). They found that the extent of the boundary-controlled rip current varies depending on the strength of the longshore flow. The rip is active till the tip of the coastal structure during strong longshore current. If tidal currents and wind/wave currents oppose each other, resulting in a mean longshore flow close to zero at the tip of the structure, then rip currents can extent for more than a 100 meters from the surf zone.

Open beach rip current rescues in the Netherlands appear at surf zones with significant vertical variation in bottom topography, indicative of bathymetric rip forcing, channel rips to be precise. However, also hydrodynamical rip currents can appear along the Dutch coast. Open beach rip currents are still strongly related to longshore currents. When longshore velocity and onshore velocities are in the same order of magnitude, rip currents can occur. No open beach rip currents were observed at Scheveningen when longshore current velocities were approximately three times larger than cross shore velocities, this corresponds with an on-beach wave incidence larger than 15 degrees (*de Zeeuw, 2011*). Open beach rip currents are strongest with wave heights between 0.5 and 1.0 meters. So, it is not: the bigger the waves, the stronger the rip current. This is because physically, under lower waves, the absence of breaking in the channel reduces onshore forcing through Stokes drift and broken wave bores, allowing a dominating exit flow. (*Castelle et al., 2016*). Between straight offshore currents and alongshore currents there are oblique troughs, flowing seaward at a certain angle due to longshore current push. Measurements at Scheveningen by de Zeeuw (2011) showed that oblique velocities are almost twice as high as straight offshore directed rips in the Netherlands, reaching 0.45m/s and 0.25m/s respectively. This is supported by the drifter simulations of Winter (2014) in Egmond (Figure 7). Due to a strong feeder current, the oblique trough can have an offshore extent of >100m, while the straight offshore rip does not extent further than 20 meters from the surf zone. Longshore velocities can reach up to 0.5m/s on a beach with groynes and 1.3m/s on an open beach (*de Zeeuw, 2011*).

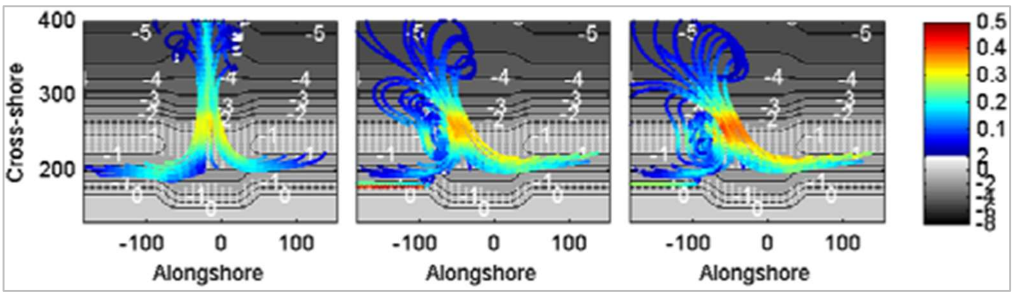

Figure 7 - Differences in flow speed between rip obliquities (Winter, G.., 2012)

2.4. Human factors

For swimming, safety extends beyond physical factors. A large part in this subject depends on human knowledge and abilities. In Chapter 1 the very limited awareness of beachgoers was already mentioned with the studies from Uebelhoer (2022) in Australia about the identification of rip currents in picture and Pitman (2021) in New Zealand focussing on the identification in real life. The lack of rip current knowledge/recognition is not the only human factor causing high rescue numbers.

In the Netherlands the KNRM and Reddingsbrigade are using warning flags, established by the International Life Saving Federation (ILS), to inform bathers in the Netherlands about possible dangers and if swimming is responsible (Appendix B1 - Warning flags and recognition). But how well is the ***flag knowledge*** of bathers and do they follow the corresponding instructions? Research reveals a concerning gap in flag knowledge among bathers with a notable lack of understanding for flags other than the red one (*Roefs et al., 2023*) (Appendix B2). 50% of the respondents considered the yellow flag as safe and even 75% of beachgoers would go into the water. Even more alarming is that most of the people rather tend to go into the water under a yellow flag than under a yellow-red flag, while a yellow flag means: pay attention, medium hazard, and the yellow-red flag means: recommended swimming area, lifeguards present. Only 3,4% of the respondents correctly understood the meaning of the yellow-red flag. This lack of awareness on the definition of warning flags means an increase in safety risks at the beach.

From a research in Australia, it was noticed that a lot of people swim at ***unpatrolled beaches***. The main motivation for their decision to visit unpatrolled beaches was that it is either the most nearby beach, they heard from family/friends that it was nice, or that it is too crowded at patrolled beaches (*Uebelhoer, L. et al., 2022*). Although there is no comparable study specifically for the Netherlands, beaches along the whole Dutch coast are busy with good weather, the unpatrolled ones most likely as well. For unpatrolled beaches it is extra important to know what you are doing because it will take time if you need to be rescued. Nevertheless, many visitors of unpatrolled beaches were infrequent beachgoers with poor beach hazard understanding. Still 85,6% intended to enter the water for a swim despite being aware that there were no lifeguards active according to Uebelhoer. This indifference to the presence of lifeguards raises concerns about potentially dangerous situations and drowning incidents.

Swimming ability looks like an obvious thing, but it is important to question if people can really swim as good as they think they can. There are a lot of people overestimating their competences when it comes to swimming. They either do not see the real risk and power of the sea or think they can handle it because they have been at the location a lot. A research in New Zealand looked at the swimming abilities of beachgoers and revealed that 32% of the beachgoers could only swim twenty-five metres or less (*McCool, J. P. et al., 2008*). This number is similar to earlier studies about swimming competence. Both the Netherlands and New Zealand are countries with a high reported swimming competence and a low percentage of fatal unintended injuries caused by drowning (Borgonovi et al., 2022) and are therefore comparable. If people get caught in a rip current, they often do not know exactly how to act. The traditional advice is to swim right or left to escape a rip current. However, swimmers have almost a 50 % chance of swimming in the wrong direction (against the longshore current) and hence be pulled back into the rip (*Leatherman., 2011*). Staying afloat and go with the flow till help arrives or till you automatically flow back due to the circulatory nature of some types of rip currents is the best approach (*Brander and MacMahan., 2011*).

The combination of swimming competence and lack of risk perception leads to very risky and dangerous situations. A conservative “rule of thumb” is, according to Hanes (2016), that the deepest water a novice beachgoer should reach, even during the passage of wave crests, is a depth that only reaches the persons thigh, that is, between the knee and the waste.

2.5. Research questions

Globally, but particularly in the Netherlands there is not a lot of research done on rip currents and even less on the coupling between rip currents and rescues. Information is especially sparse when we speak about wind-wave dominated systems. The challenge of predicting when and where rip currents occur adds to the complexity. Accordingly, the main question of this research is: **Under what circumstances do rip currents pose the greatest threat for bathers along the Dutch coast?**

To get to an answer the following sub-questions have been formulated:

1) When did rip current related rescues most frequently occur?
    - Were the available data suitable to provide an overview?
2) What were the prevailing boundary conditions during these situations?
    - How did weather, waves and rips interact?
    - Were there days with similar conditions as days with multiple rescues? And if so, were there rip current related rescues on those days as well?
3) How did rip current hazards differ along the Dutch coast?

As a follow up to de Zeeuw (2011) and Winter (2014) their studies, this research will go into the dominant parameters of rip current development in combination with rip current related rescues. Data for this research is provided by Rijkswaterstaat, the Dutch royal meteorological institute (KNMI), the Dutch institute for safe swimming waters (NIVZ) and the Reddingsbrigade. By addressing the questions mentioned above, this research aims to improve our understanding of rip currents, enabling more effective safety measures and timely warnings, in the end contributing to better beachgoer safety along the Dutch coast.

3. Methodology

This chapter outlines the methodology used to answer the research questions. First, the different field sites are introduced, followed by the sources of the used weather, water, and rescue data. Furthermore, pre-processing of the rescue data and data analysis are outlined.

3.1. Field sites

Three different locations along the Dutch coast – Egmond aan Zee (hereafter referred to as Egmond), Scheveningen beach in The Hague (hereafter referred to as The Hague) and Monster – were selected for investigation (Figure 8). Although The Hague and Monster are situated close to each other (≈12km), two artificial structures, the Zandmotor north of Monster and the jetties at Scheveningen harbour potentially impact the local water dynamics. The biggest difference between The Hague/Monster and Egmond is the angle of the coastline. Egmond is located more to the north with the coastline just tilted seven degrees eastward with respect to the north. Meanwhile, the coastline of The Hague and Monster is located more to the south with a 48-degree eastward angle. Bathymetrically speaking, the beaches only differ a little, the beaches of The Hague and Monster are characterized by a general beach slope of 1:35 (meaning 1meter height difference over 35 meters of beach) while the North–Holland coast of Egmond has a gentler beach slope of 1:45 to 1:60, respectively (Huisman et al., 2015).

The topographical changes of the intertidal areas at the beginning of each summer season are detailed in 'Appendix C – Field Site Situation' with a few notable details. (1) A clear sand bar system is visible in especially Egmond, but also in Monster. (2) In Monster the groynes, protecting the coast from erosion, are clearly visible. These groynes are also present in The Hague where they are most visible in 2023. (3) For all sites the sand replenishment cycle is visible. In Egmond they started in spring 2023 with a new cycle according to Rijkswaterstaat, explaining the differences in the bar pattern between 2022 and 2023. In The Hague a slight form of erosion is visible over the years decreasing the beach width, this corresponds to a replenishment conducted in 2016 and the last one at the end of 2023 (after the last satellite image). In Moster changes are visible as well, especially between 2022 and 2023 while no sand replenishments were conducted over the last years. The fact that sand is mainly added at the northeast side of the groynes suggests it coming from that direction, supplied by the Zandmotor. Besides bathymetrical differences the average environmental parameters slightly differ over the sites (Table 1 & 2), but without any big noticeable differences. For the wave direction all locations showed peak occurrences from both the north/northwest and southwest, the wind is evenly distributed.

Table 1 – Averaged environmental parameters Egmond (2020 – 2023) (Source: KNMI and Reddingsbrigade)

Wave period	Water level	Wave height	Wave angle	Wind speed	Wind angle	Temperatu	Sunshine	Rainfall
5.50 sec	-6.57 cm	107.00 cm	N/NW & SW	7.27 m/s	NOZW	11.69 °C	2.40	0.96 mm

Table 2 – Averaged environmental parameters The Hague / Monster (2020 – 2023) (Source: KNMI and Reddingsbrigade)

Wave period	Water level	Wave height	Wave angle	Wind speed	Wind angle	Temperatu	Sunshine	Rainfall
5.08 sec	-0.46 cm	126.40 cm	N/NW & SW	6.86 m/s	NOZW	12.09 °C	2.47	1.00 mm

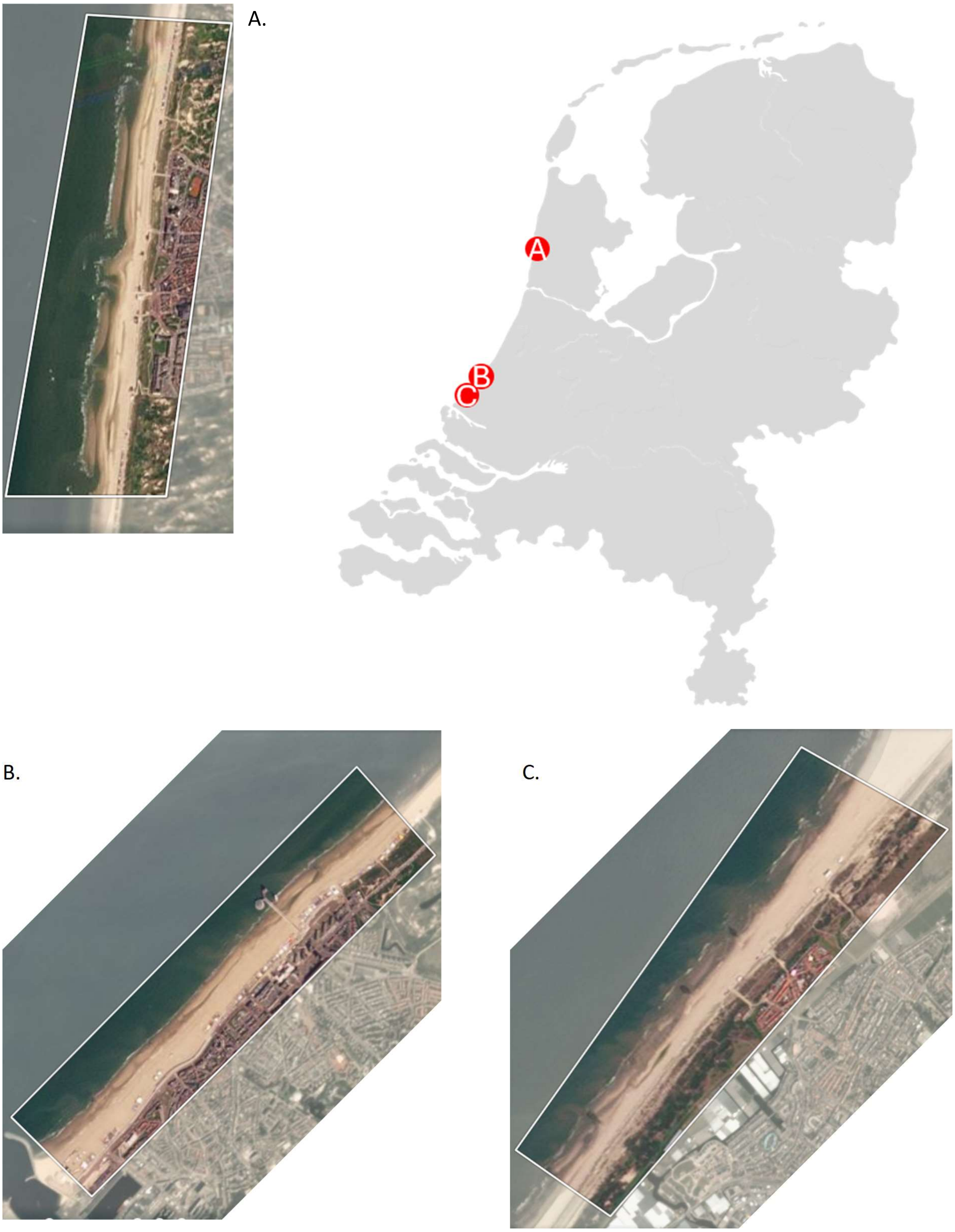

Figure 8 - Different study sites, A: Egmond (aan Zee), B: The Hague (Scheveningen) and C: Monster

3.2. Data sources

Critical data for the research were sourced through collaboration with various organizations. Most important, the rescue data were provided by the lifeguards of Egmond, Monster and The Hague from the beginning of 2020 till the end of the summer in 2023. The data was facilitated by the NIVZ, the Dutch institute for safe swimming waters. Initially, the idea was to look at various locations spread along the entire Dutch coast, preferably including one of the Wadden islands and Zeeland. Unfortunately, due to an insufficient amount of information this was not possible. The Egmond collaboration was therefore crucial to keep the possibility of comparing rip related rescues across different coastline angles.

The received data Excel document contained datetime, location (often most nearby beachclub), priority of the call, brief description of the incident and the number of people involved. Between the study sites there were some clear differences within the data. Egmond kept the information basic, while The Hague and Monster provided additional information, especially from 2023 onwards. Here, besides the data above the exact coordinates were added, together with the first and second tides (height and time), the wind direction and how crowded the beach and surf zone was (no people, calm, moderate, busy, very busy). Table 3 is an example of the incoming data in The Hague, in 2023. The total number of registrations in the datasets differed between sites. For Egmond only the bather/swimmer registrations were sent through, 87 noted incidents in four years. The total dataset of The Hague came to 4005 notations, of which 302 were bather/swimmer related. For Monster this were 950 incidents in total with 58 bather/swimmer related, respectively.

Table 3 – Example of given rescue information The Hague 10-03-23 (Source: Reddingsbrigade The Hague)

Datum	Tijdstip begonnen	Tijdstip afgerond	Prio	Commandopost	Hulpverlening	Eenheden	Levensbedreigend
2023-08-10	18:18:00	18:25:00	P2	15-8811 hoofdpost noord	P2 Waterhulpverlening	15-8820 (Tom Baak)	Nee

Type	Subtype	Hulp aan personen	Geredde personen	Locatie lengtegraad	Locatie breedtegraad	1e hoog water	1e laag water
Waterhulpverlening	Zwemmer	2		4,27853349	52,11489838	87 (10:54:00)	87 (06:25:00)

2e hoog water	2e laag water	Strandbezoek	Aantal baders	Branding	Windrichting	Omschrijving
87 (23:20:00)	87 (18:49:00)	Rustig	Matig	Hevig	ZZW	2 personen uit de mui teruggehaald, 3 voorzwemmers

In addition to the rescue data, weather and water data is indispensable for linking the rescues and environmental parameters. Hourly weather data for the research locations consisting of wind, temperature, sunshine, and rainfall were obtained from the KNMI, the Dutch institute for meteorology. The water data, including wave direction, wave period, wave height and water height, collected at a ten-minute interval were obtained from Rijkswaterstaat. For this research two different measuring stations were used: the 'Munitiestortplaats' station 40km offshore of Ijmuiden to combine with the rescue data of Egmond and the 'Eurogeul' station, 30km offshore, for the data of The Hague and Monster. The error values (e.g. NaN or 99999) were not included in the calculation of the average, which was possible because there was such a low number of missing values at times of the rescues. Only on one occasion in Egmond (08-07-2020) there was no data available at the time of a rip related rescue, resulting in a missing wave direction for that specific rescue.

3.3. Data pre-processing

This section delves into the process of preparing and refining the data before analysis. It covers the identification of rip current related rescues, adjustments for wave refraction, calculation of average values, and the comparison with similar parameters.

3.3.1. Rip current certainty

From the initial data description, it was unclear whether rescues were rip current related or not. Therefore, the first step in this study was to look at the summer months (May – September) and derive the rip current relation of the rescues. Based on specific keywords three categories were formed: (1) certainly-, (2) probably- or (3) possibly rip current related. Category 1 is only for the rescues with the explicit word 'rip current' in the description. When the description mentioned something about danger flags, a combination of breakwater/dam with currents or people having trouble coming back due to a current the rescue is placed in category 2. Finally, category 3 is applied if the description mentioned something about a dam/breakwater or current individually, so these rescues were possibly related to a rip current. For the rest of the study, only the category 1 rescues are used unless mentioned otherwise. In that way this study stays as close to the facts as possible

As shortly indicated in Section 3.2 the number of rescues highly differed between sites, so did the amount of rip current related rescues. Egmond recorded a total of 90 swimmer related rescues between the beginning of 2020 and the end of 2023. Out of the 90 rescues there were 16 rescues definitely related to rip currents, there were two category 2 rescues, and 19 category 3 rescues when following the criteria mentioned above. From the 16 cat. 1 rescues three took place in 2020, nine in 2022 and four in 2023. So, in 2021 there were no rescues related to rip currents, whether this is because there simply where none or because a lack of notation is uncertain.

The beach of The Hague is one of, if not the most popular beach in the Netherlands and recorded a total of 4005 actions over the four-year timeframe. Nevertheless, most of the actions had nothing to do with rip currents. 52 rescues certainly did, 17 rescues fitted the category 2 criteria and eight rescues to the criteria of category 3. Out of the 52 rip related rescues 10 rescues occurred on the same day, the 10th of August 2023. Due to some unique parameter values this day distort the diagrams in some cases. The 10th of august will be further discussed in Section 4.4. The distribution of rip related rescues over the years was as follows: in 2020 there was only 1, in 2021 there were 15, in 2022 17 and to in 2023, there were 20. In about 10 of the category 1 rescues both the words 'rip current' and 'breakwaters' or 'piers' appear in the rescue description. With the 52 rescues in total this forms a (weak) link to the rip currents being caused by the (nearly) emerged breakwater during lower tides.

For the beach of Monster 950 actions were noted, of which 19 category 1 rescues, 16 cat. 2 and 44 cat. 3. One of the reasons for the large number of category 3 rescues is the unclear description. Often rescues are described as 'guidance dam 11 north' or 'person in trouble dam 10 north'. When a rescue is close to a dam there is a chance that rip currents were part of the problem but without a mentioned seaward current there it is no guarantee. The distribution of rip related rescues over the years is as follows: in 2020 there were six, there were five in 2021, five in 2022, and in 2023, there were three certainly rip current related rescues (cat. 1).

3.3.2. Wave refraction

To enhance the realism of results, adjustments were made for certain parameters, including wave direction. First, waves will be studied by the wave incidence angle. Meaning that 0 degrees is straight onshore, a negative angle more from the south and a positive angle more from the north. When comparing these angles to the angles given by a regular wind rose it differs between Egmond and Monster/The Hague due to the differences in coastline angle with respect to the north. After that, the principle of wave refraction is applied. In nature, waves are moving towards the shore in a certain angle, a decreasing depth is causing the wave trains to slow down. The wave frequency remains unchanged, but the wavefronts get packed more closely together and align with the elevation depth contours of the sea floor (*Gamito, N. & Musgrave, K., 2002*) (see Figure 9). The wave refraction is calculated by a formula using the wave incidence angle and the phase speed of the waves. Assuming a uniform coastline the formula looks like this: (*c2/c1)*sin(Waveangle*). Here, the phase speed is calculated by using the wave period and the water depth. Wave angles from Munitiestort and Eurogeul were projected to 20m depth. In that way the data of the Eurogeul station and the Munitiestort station can be better compared despite the different distances and depths between measuring station and beach. Therefore all the figures in this research about wave angle will contain the refracted shore normal angle.

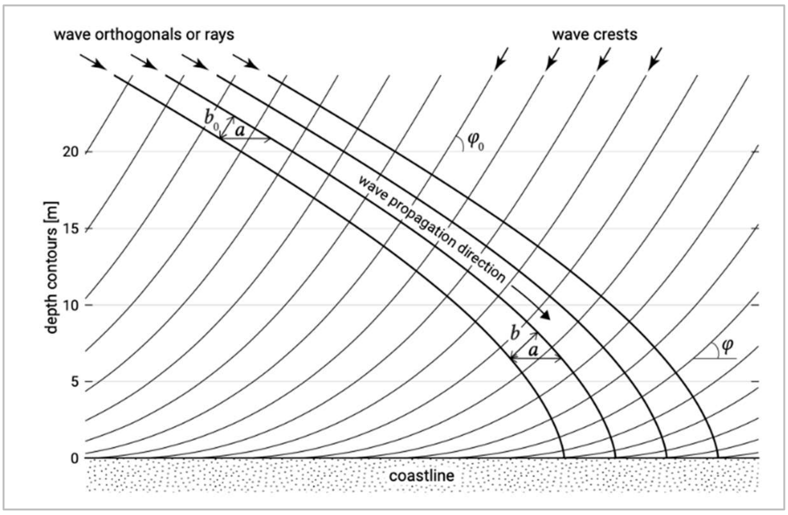

Figure 9 - The principle of wave refraction (Bosboom and Stive., 2023)

3.3.3. Coupling rescue data and environmental parameters

A crucial step in the research was to couple the environmental weather and water data to the rescue data, to explore the connection between dangerous rip current occurrences and environmental parameters. For this, the two-hour average prior to the rescue event was used, instead of instantaneous environmental parameter values at the time of a rescue. This was done to achieve a more average number over the time that the rip currents were activated. The outcomes are presented in various diagrams in the next chapter. The rescue related environmental data were compared to the data over the total four-year period, to see if the trend between the two was similar or that rip rescue data showed unique values. Wind and wave roses were made and finally, all the available data was used for a comparison between the different study sites.

Another question arising from parameter comparison was if there were days with similar environmental parameters as the days containing rip related rescues. If so, were there any rescues on those days as well and otherwise, why not? This is investigated for four different days with three or more category 1 rescues: two days in The Hague, one in Egmond and one in Monster. For each day two target values representing the significant values of that day were used, with a buffer to account for small variations. To reduce the analysis to the moments that bathing and swimming is expected, some assumptions were made to reduce the data. This is done by filtering on (1) seasons, so only include the summer months (May till September), and filtering on (2) air temperature, with a minimum of 17 degrees Celsius.

4. Results

In this Chapter the results are shown for the different locations: Egmond, The Hague and Monster. The last part of this chapter zooms in on the extraordinary days with three or more rescues and compares them with days out of the entire dataset that show similar parameters. With that, this chapter is providing valuable insights into the complex situations of local conditions and rescue incidents, laying the foundation for further research and improved safety measures.

4.1. Egmond

As mentioned in Section 3.3.1, Egmond recorded a total of 90 rescues between 2020 and 2023. 16 of these rescues were related to rip currents. From these rescues three took place in 2020, nine in 2022 and four in 2023. In 2021 there were no noted rescues related to rip currents. The results here are showed in three types of diagrams. (1) The comparison bar graphs, here the blue bars with the left y-axis represent the entire four-year dataset and the red bars with the right y-axis represents the dataset of rip current related rescues. (2) The stacked bar graphs show the distribution of environmental parameter related values over the four years, focussing on only the rip current related values. Finally, (3) Wave roses are plotted to show the angle in which waves arrive to shore. The colour stands for the wave height belonging to that specific angle. Parameters that did not show any outstanding values are added in Appendix C.

For the rescue related water data, the 16 rip related rescues in Egmond seemed to occur most often with waves from the southwest (Figure 10a), despite a northward wave dominance over the total four-year timeframe. However, still six of the 16 rescues took place with waves from the northwest. Looking at how these numbers are distributed over the years there is a clear shift in rip related wave angle (Figure 10b). In both 2020 and 2022 only one rip related rescue was needed with northwestern waves, while in 2023 all rip related rescues (4) took place with waves from the northern direction, of which three on the same day. Besides the north south distribution of rip related waves, there are no rip related rescues with shore-normally incident waves and those with angles smaller than 20 degrees with respect to shore normal. This coincides with the long-term timeframe where straight onshore waves are at first less common, but also coincide with lower wave height (Figure 11) and a lower wave period (Appendix D – wave/period rose Egmond).

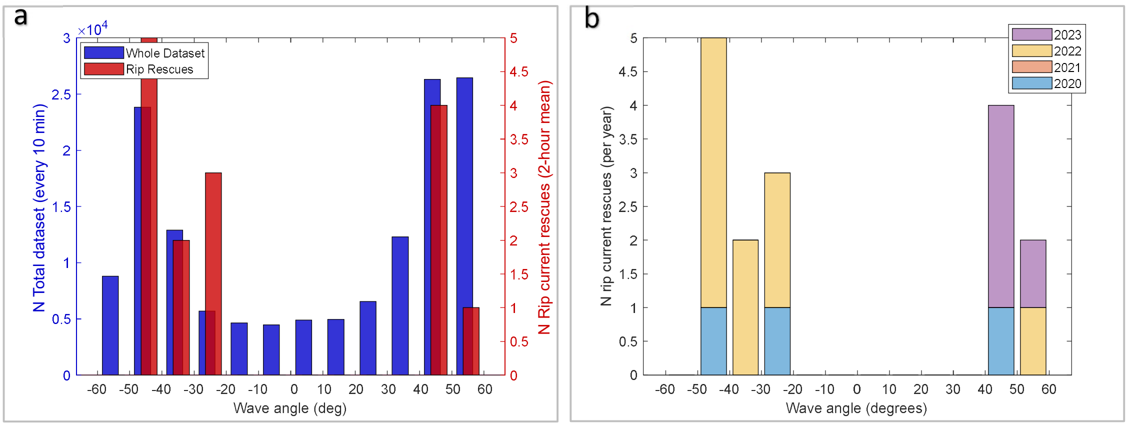

Figure 10 a & b – Incoming wave angle Egmond, total dataset vs rip related (a) and rip current related over the years (b)

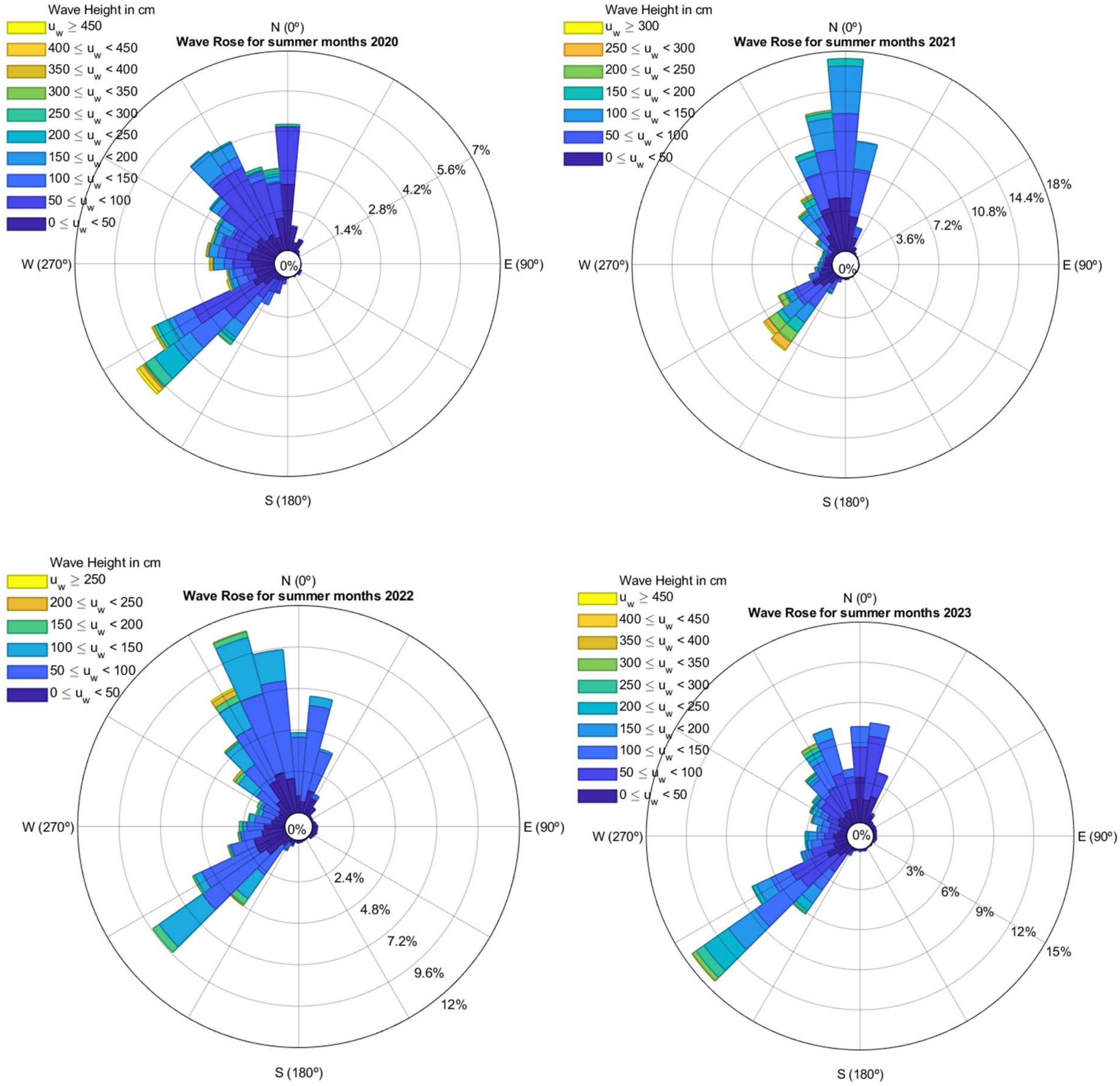

Figure 11 – Wave roses for the years 2020 till 2023 (total dataset)

Beside the wave direction, the water height data shows that the majority (11 out of 16) rip related rescues took place with water levels below 0 NAP (Normal Amsterdam Water Level) (Appendix E). There was no specific trend in either rising or falling tide.

The weather data shows quite a few fluctuations in wind speed and direction. What stands out is that most of the rescues seem to happen after a peak in the windspeed, typically 5 to 12 hours after the peak (Figure 12). In this figure the blue line represents the windspeed over the days and the red vertical lines represents the cat. 1 rescues. When the wind weakens and the weather gets better the waves are still powerful which leads, with the right water height, to an increased risk of rip currents. The wind direction did not show an as clear trend as the wave direction but was in most cases directed towards the land. Actually, there was only one rescue related to offshore winds (Figure 13a). The temperature did not coincide with the average of the total dataset (Figure 13b). A sidenote here is that the temperatures being linked to rescues were often not the seasons highest. Other environmental parameters showed similar value trends as the four-year dataset (added in Appendix F).

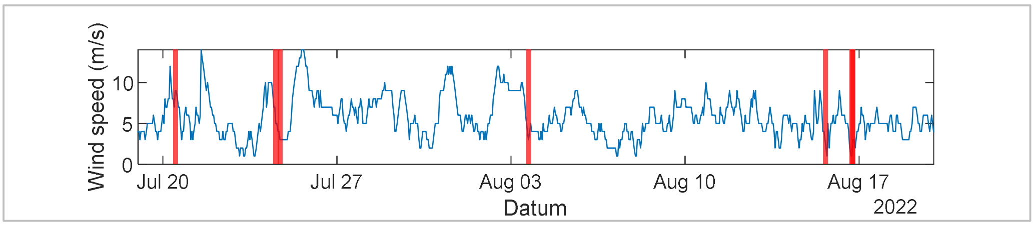

Figure 12 – Wind speed variations with the peak often before the rescue.

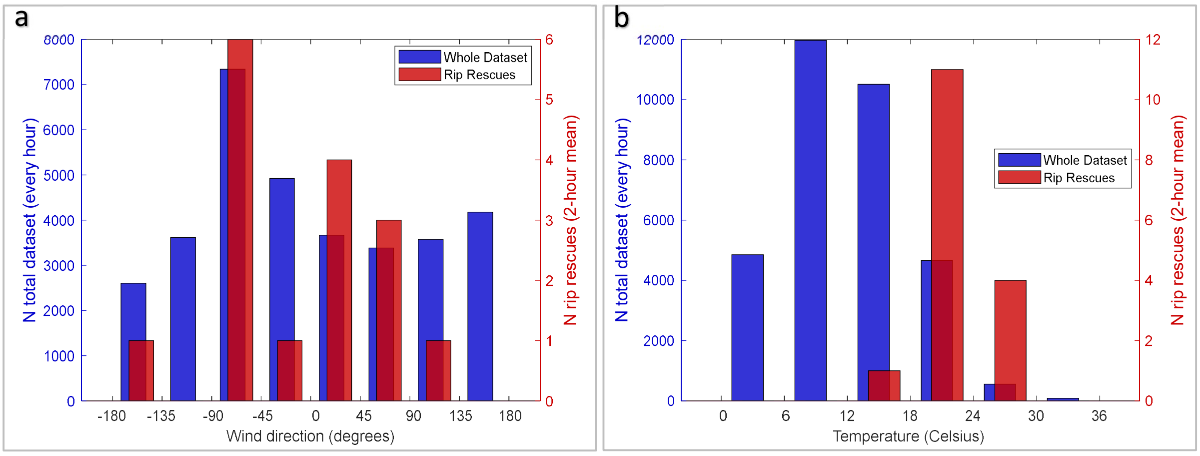

Figure 13 a & b – Total dataset vs rip current related Egmond, incoming shore normal wind angle (a) and Temperature (b)

4.2. The Hague

The popular beach of The Hague recorded a total of 4005 rescues over the four-year timeframe with 52 being related to rip currents. The 10th of August 2023 distorts the overview in some cases with 10 rescues. The distribution of category 1 rescues over the years is as follows: in 2020 there was only 1, in 2021 there were 15, in 2022 17, and in 2023, there were 20 rip related rescues.

The water data in combination with the rip related rescues suggests that dangerous rip currents at The Hague especially occur with waves arriving from positive shore normal directions, Figure 14a confirms this. Out of the 52 rip related rescues 43 were conducted with waves from the north. This is not in line with the total dataset, where waves from the southwest were dominant over the 4-year period. Despite some visible fluctuations over in the yearly wave roses (Figure 15)(Appendix G for wave period), the rescue related data is uniformly distributed over the years. As an example for this observation the yearly distribution of the wave angle is added in Figure 14b.

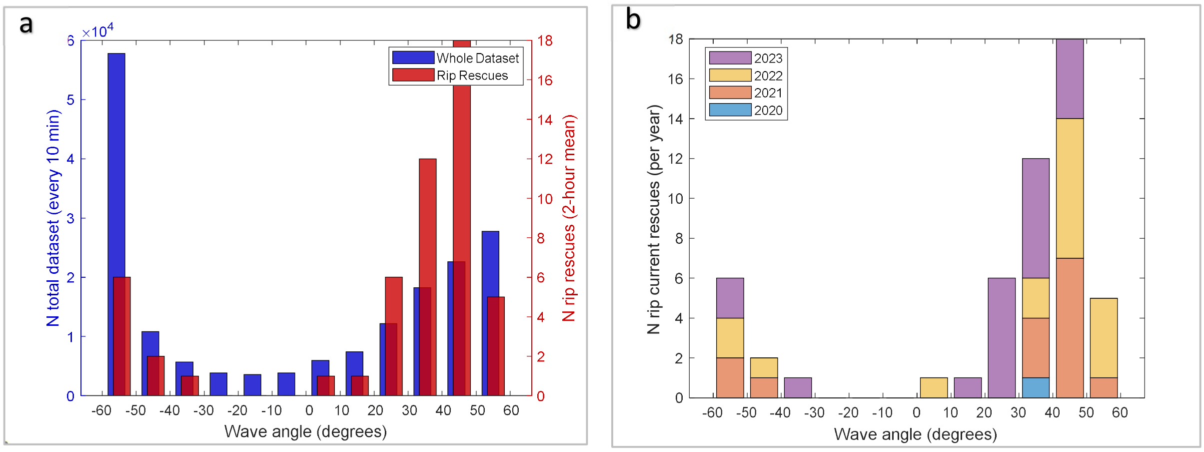

Figure 14 a & b – Incoming wave angle The Hague, total dataset vs rip current related (a) and rip current related over the years (b)

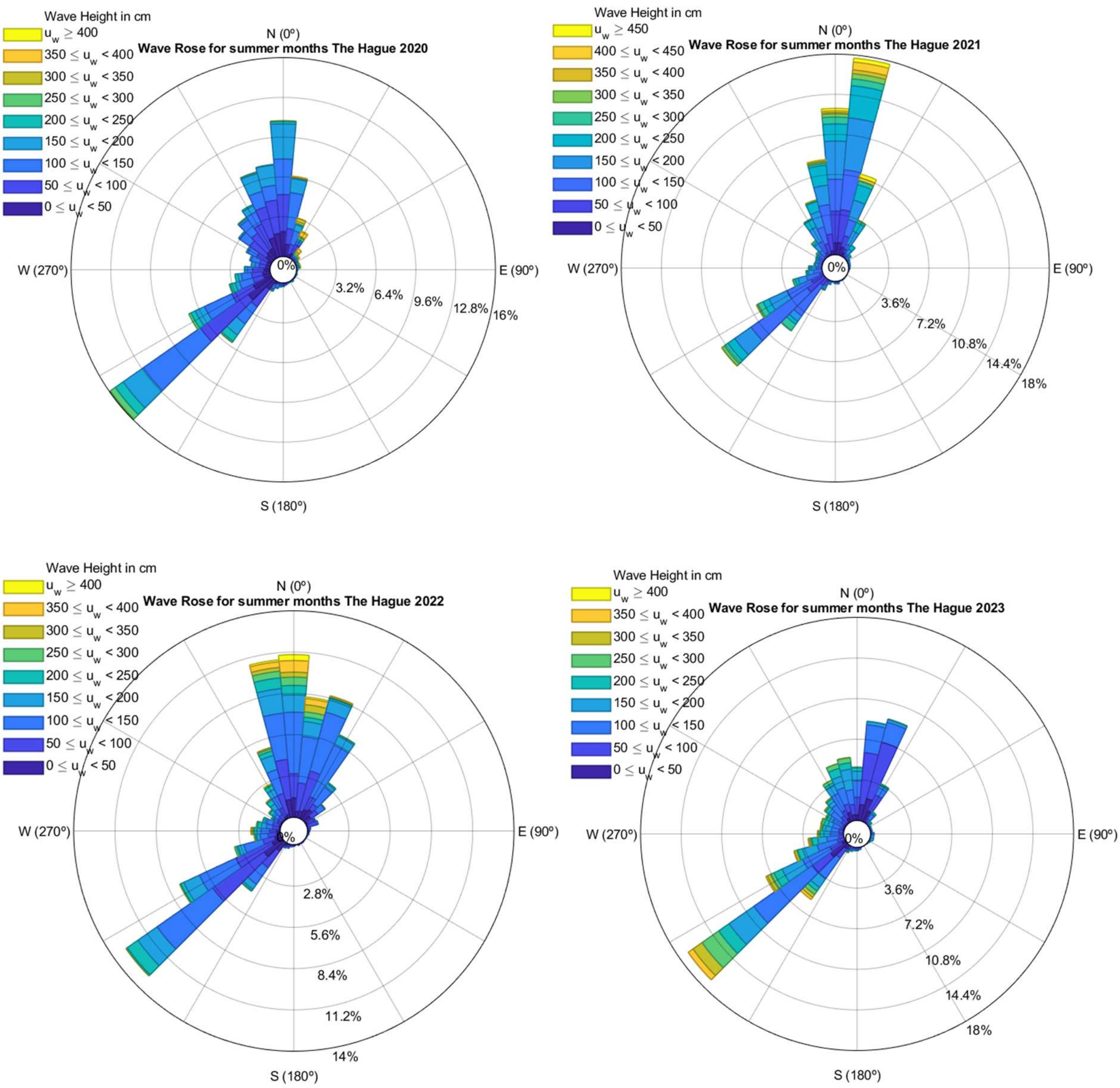

Figure 15 – Wave roses for the years 2020 till 2023 (total dataset)

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Furthermore, the data show that the water level during most of the rescues (39x) is below NAP (Figure 16a), just like Egmond. For the weather data in The Hague, it turns out that the trend of the wind direction is in sync with the trend of the wave direction, so during most of the rescues the wind blowed from a northerly direction (Figure 16b) with a southerly dominance over the four-year period. In only 10 cases the wind came from negative shore normal regions, which is from the west / southwest. Parameters like sun and temperature were again not in sync with the trend of the entire dataset as temperatures during rip current related rescues were often higher than the most frequent values over the years. Other environmental parameters were like the overall trend (Appendix F).

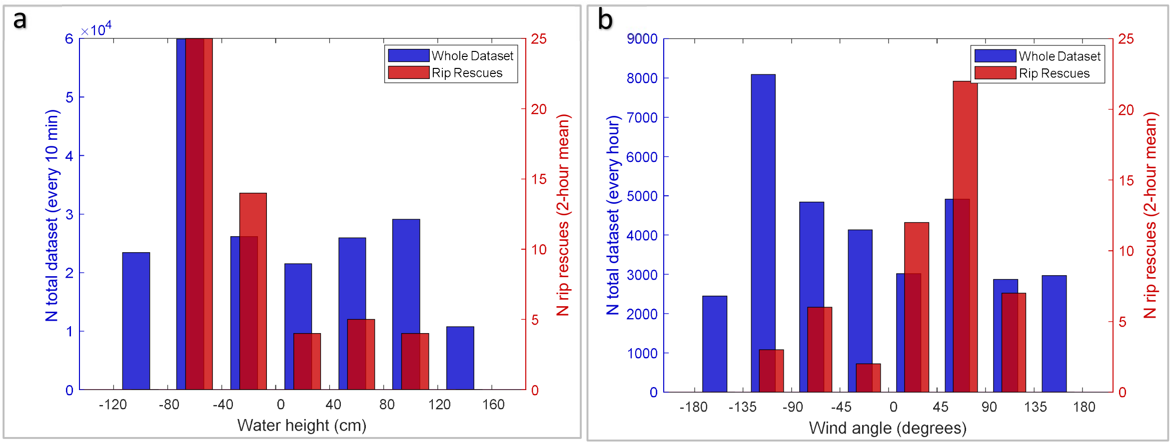


Figure 16 a & b - Total dataset vs rip current related The Hague, Water height (a) and incoming Wind angle (b)

4.3. Monster

For the beach of Monster 950 rescues were noted of which 19 belonged to the category 1 rip current relation. The distribution of these rescues over the years is as follows: in 2020 there were six, five in 2021, also five in 2022 and three in 2023.

For the rescue related water data in Monster, it is again the wave angle that immediately stood out (Figure 17a). Only during two of the 19 rescues the waves came from a southwestern angle. Like The Hague, the overall data from Monster showed the waves from a southwestern angle as dominant over the four-year period, especially the very oblique incident waves. Direct onshore waves did not cause any danger. In fact, with angles smaller than 30 degree with respect to shorenormal there were no rip related rescues noted.

The wind angle showed the same trend as the waves, a dominant rip related wind from the north and a dominant overall wind from the south (Figure 17b). For the other environmental parameters the trends of the entire dataset and and rip current related dataset were really close. The water height was mainly negative, wave height mainly within the range of to the most common values over the whole dataset (25 – 150cm), just like the wave period (4 – 6 sec) and wind speed (4 – 10 m/s) (Appendix H). Temperature and sunshine again did not coincide with the four-year trend, similar to other locations.

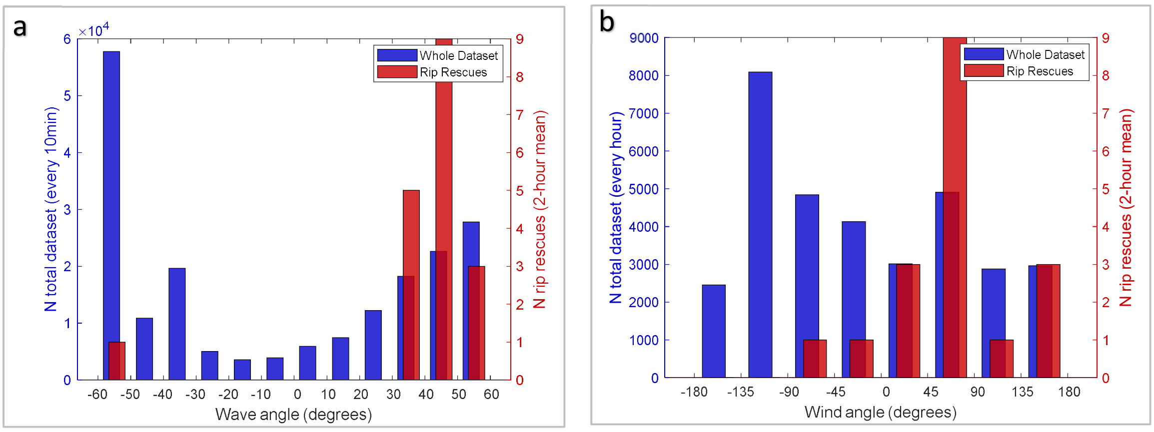


Figure 17 a & b - Total dataset vs rip current related Monster, incoming wave angle (a) and Wind angle (b)

4.4. Analysis of high rescue days

There are several extraordinary days where three or more rip related rescues occurred on one location. Over the 4-year timeframe this happened four times on the studied sites, shown in Table 4. These high rescue days will be discussed in this chapter and compared to days with similar parameters. The two most significant values are taken each time and searched in the dataset within a buffer (≈10%). In that way two values are guaranteed to be similar but other values may still differ and be a plausible reason why rip related rescues did, or did not occur that day. The goal in this chapter is to identify patterns and parameters contributing to a dangerous swimming environment. In Appendix I the local situation near the rescues events is showed by satellite imagery.

Table 4 – High rescue days

Date	Location	Rescues
9-8-2020	Monster	4
17-7-2021	The Hague	3
20-7-2023	Egmond	3
10-8-2023	The Hague	10

4.4.1. Monster, 04-08-2020

Table 5 – Environmental parameters Monster, four rescues

Wave angle / Ref SN	Wave period	Water height	Wave height	Wind dir SN	Wind speed	Temperature	Sunshine
350 / 38 deg	4,6 - 5,4 sec	-54 - 62 cm	144 - 161 cm	58 - 73 deg	7,5 m/sec	27,5	10

The first day with more than three rip related rescues was on 04-08-2020 in Monster. The parameters of this day are shown in Table 5. The most significant parameters chosen as target values for this case are the temperature and wind direction. It was a very warm and sunny day, with still a powerful 4 bft wind from a northern direction. Searching in the dataset for days with similar temperatures and windspeed showed that in most cases the wind comes from the south/southeast with these temperatures, which is slightly offshore. This makes sense since warm air often comes from the southeastern regions. Also, wind direction may not be a key factor for rip current existence, but previous results showed that rip related rescues rarely appeared with offshore winds. In the whole dataset there is only one day where the parameters in the afternoon were practically the same, 10-06-2023. On this day there were two reported rip related rescues as well and therefore we can say that the unique wind and temperature combination on 04-08-2020 highly enlarged the rip related danger.

4.4.2. The Hague, 17-07-2021

Table 6 – Environmental parameters The Hague, three rescues

Wave angle / Ref SN	Wave period	Water height	Wave height	Wind dir SN	Wind speed	Temperature	Sunshine
358 / 46 deg	4,7 sec	-59 - -34 cm	187 cm	47 deg	8,3 m/sec	19,8	10

For the second day with three or more rescues we go to The Hague, on 17-07-2021. On this day three rip related rescues were conducted with the environmental parameters during these rescues presented in Table 6. In contrast to the day mentioned above in Monster, all parameters were close to the dataset average as given in Section 3.1. The wind speed is quite high, and it was fully sunny but furthermore the values were common. Because the water related parameters showed no outstanding values, the wind direction and wind speed were taken as main characteristics of the day. Like expected there were a lot of days with similar values. On some of these days there were rescues but on most of the days there were none. So, the windspeed and direction on this day did not give any new insight on the occurrence of rip current danger. The satellite image in Appendix I showed some possible rips in the bar system and the groyne is also clearly visible which could be the cause of the danger.

4.4.3. Egmond, 20-07-2023

Table 7 – Environmental parameters Egmond, three rescues

Wave angle / Ref SN	Wave period	Water height	Wave height	Wind dir SN	Wind speed	Temperature	Sunshine
324 / 47 deg	7,5 sec	-59 - 45 cm	70 - 84 cm	38 - 68 deg	4 m/sec	17	8

The third day with three or more rip related rescues was on 20-07-2023 in Egmond. In Table 7 the parameters during the rescues on this day are shown. For this day a clear bar pattern was visible in the satellite data, added in Appendix I. In Section 4.1. it was mentioned that during most rip related rescues in Egmond the waves arrived from a southwestern angle, at least in 2020 and 2022. This day with three rescues represents three of the in total four rip related rescues in 2023, all with waves from the northwest. Beside the wave direction the wave period (7.5 sec) is high in comparison with the overall average period of 5.5 sec. Therefore, the wave direction and wave period were taken as target values. For these parameters a lot of similar values were obtained within the four-year dataset, but without any other rip related rescues. With the limited rescue data available for this location, it is difficult to really come up with results. Nevertheless, it seems that the target values of this day are not the key to rip current related incidents in Egmond.

4.4.4. The Hague, 10-08-2023

Table 8 – Environmental parameters The Hague, ten rescues

Wave angle / Ref SN	Wave period	Water height	Wave height	Wind dir SN	Wind speed	Temperature	Sunshine
342 / 30 deg	7,7 sec	-58 - -28 cm	225 cm	78 - 113 deg	4 m/sec	21	9

The fourth and last high rescue day was in The Hague on 10-08-2023. A day full of sun (90%) but still high waves (225cm) and a high wave period (7.7 sec)(table 8) in comparison with the average values over the entire dataset, causing an extremely dangerous situation where 10 rip related rescues were necessary. For comparing with other days, the wave height and wave period were taken as target values. In the four-year dataset only a few days corresponded and showed similar values. When the temperature is included (>17°C)there are almost no similar days left that meet the target conditions. Only August 9, 2023, the day before, came close. A significant difference between those days is that the temperature changes and the wind angle as well, from southwest to north/northwest

(Figure 18a) According to the data this does not give the wave extra height, but it does increase the wave period a bit, and with that the wave power. Figure 18 shows a timeseries with the fluctuating blue line showing the y-values for a particular datetime and the red vertical lines shows the datetimes at which a rip current related rescues took place. The total set of parameters made this day incredibly unique and certainly enlargied the chance on rip related danger.

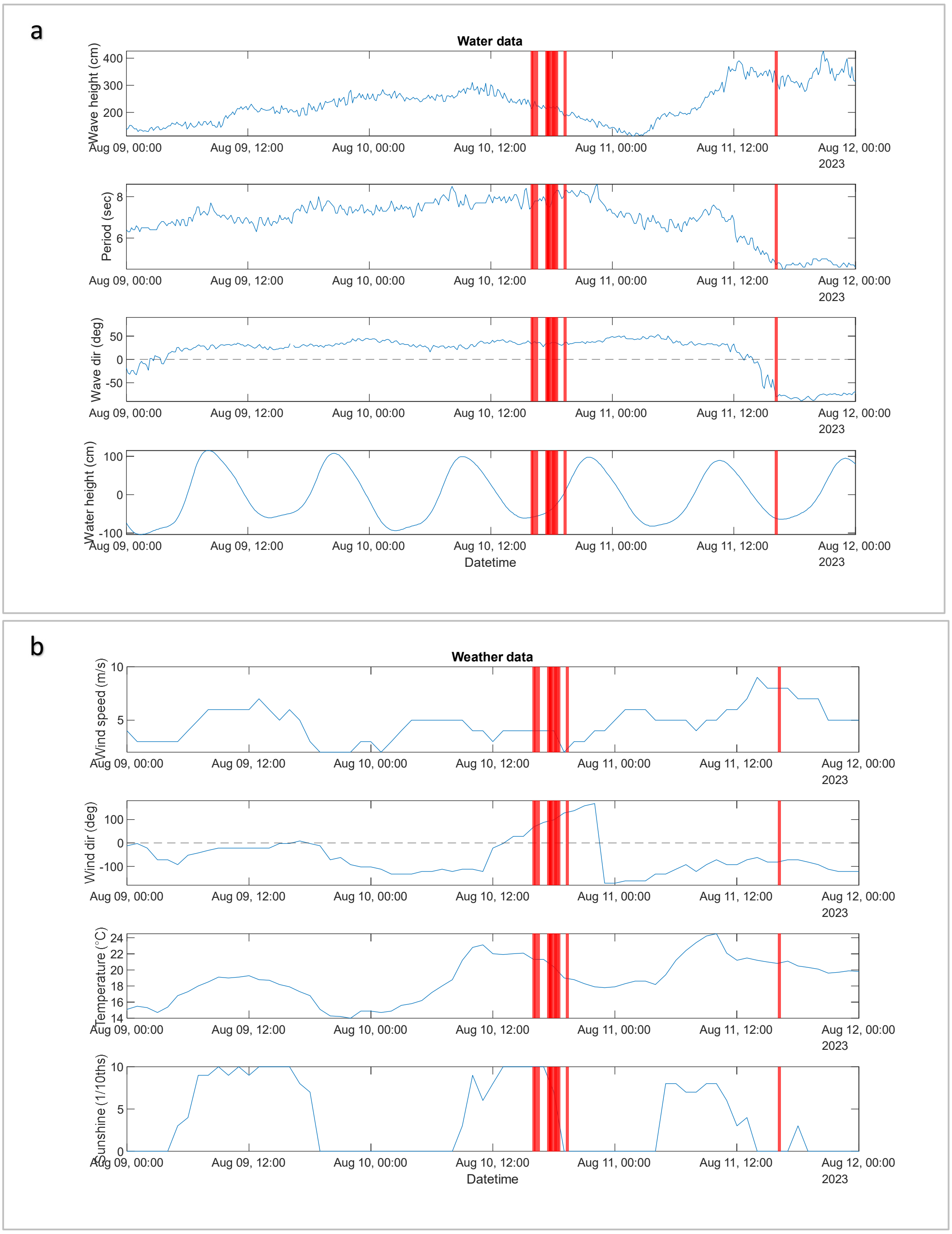


Figure 18 – Environmental water (a) and weather (b) parameters prior to the ten rip related rescues on 10-08-23.

5. Discussion

This Chapter will investigate the interpretation of differences and similarities between locations, the chance of category 1 rescue numbers to actually being higher, correlation between parameters, and the link of rip current danger with human behaviour. Finally, recommendations for further research and the development of the current system are given.

5.1. Environmental drivers for rip current related rescues

Chapter 4 showed the research results for Egmond, The Hague and Monster. This subchapter will provide an overview of the differences and similarities between the study sides.

5.1.1. Similarities

A striking similarity between the locations is the correlation between rescue incidents and some weather parameters. Despite most days being cloudy in the Netherlands, nearly all rescues were carried out with sunny, relatively warm weather. Over the 4-year period most days varied between 6 and 18 degrees Celsius while most rescues were carried out with temperatures of 18 up to 24 degrees. This all has to do with the human behaviour which will be discussed later in this chapter. The fact that rescues were not conducted during the absolute hottest days of the season can be attributed to the need of breaking waves for rip current activity. Most often at hot days there is not much wind and with that, no waves. Another factor could be that hot days are busy days on the beach, contributing to a kind of social security where people help each other when in need, mitigating the occurrence of rescues (Pers. Comm. Martin Hoogslag, NIVZ).

Rip related water height is another subject for which the values are similar over the different locations. Although there were a few rip related rescues with a positive water height, still 75% of the rescues occurred with a negative height. The difference in bathymetrical development is the most likely reason for this observation. Within the bar system the subtidal and intertidal bars are often the most pronounced. With low tide waves will break over these bars if the ratio of wave height to water depth exceeds 0.35 according to Aagaard et al. (1997). At high tide they observed that waves passed over the bar without breaking and consequently the rip current was weaker or completely inactive (Austin et al., 2010).

The locations Monster and The Hague had overall a lot of similarities in their data. Despite the fact they are only about 20 kilometres from each other, initially some differences were expected because of the Zandmotor and the harbour jetties in between the two sites. These structures could impact the longshore current which is directly related to the existence of rip currents (mentioned in Chapter 2.3). Nevertheless, the available data neither show an impact by the Zandmotor nor the harbour jetties on the rip related rescues. This only means that for rip related rescues there is no obvious difference between the locations, not that these two structures have no impact at local parameters at all. Like mentioned in Chapter 3.1 there are some developments in the last year where sand from the Zandmotor is added near the groynes in Monster. If this will impact future boundary controlled rips in Monster remains to be seen.

5.1.2. Differences

Besides similarities there were parameters that differed between the distinct locations, particularly between the 'northern' Egmond and 'southern' The Hague and Monster. The parameter in which the clearest differences for category 1 rescues were obtained is the wave angle (Figure 19a). Most rescues in Egmond were carried out under waves originating from the southwest, while most of the rescues in Monster and The Hague were carried out with waves from the north. This divergence can be attributed to the angle of the coastline. The dominant high energetic waves originate either from the north (ocean) or the south (through The English Channel). For directly onshore waves the fetch is shorter because of Great Britain, which makes them less energetic and not often dominant (also visible in Figures 11 and 15). For The Hague and Monster, the 42-degree eastward angle of the coastline seems to make the northern waves more effective for rip currents. Waves originated from the south moving through The English Channel on the other side seem to be unable to conserve their energy with this great angle of incidence. For the southern waves, The Hague and Monster are in a kind of lee of the land. This is not the case for Egmond, here due to the only 7-degree eastward angle of the coastline, waves from the southwest seem to be more impactful. Besides that, the fetch for waves from the southwest slightly increases along the Dutch coast.

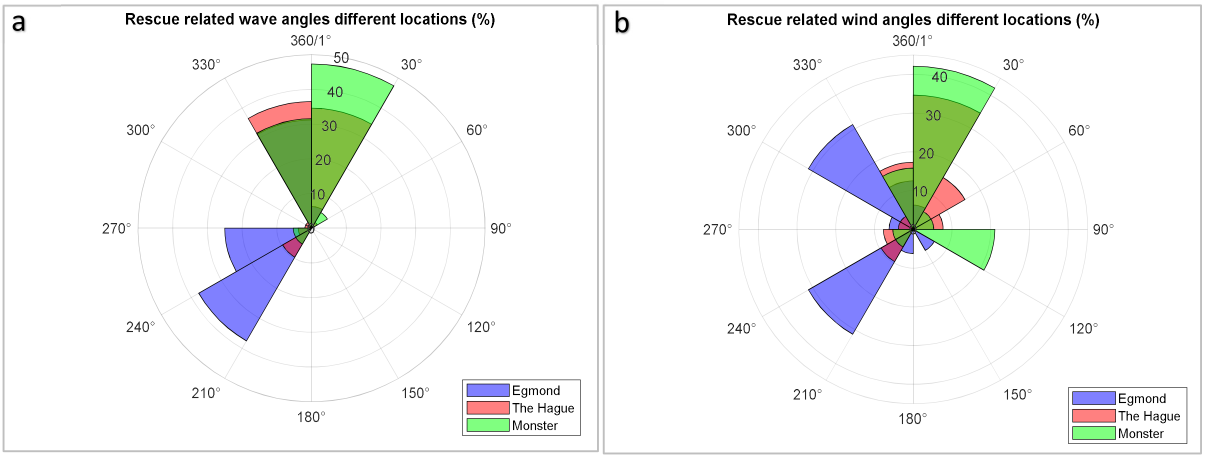


Figure 19 a & b – Rescue related angles of incoming waves (a) and wind (b)

Besides the southwest waves, the waves from the northern North sea can reach Egmond without any major obstacles under a relatively low angle of incidence as well. So, the fact that oblique waves from either direction can cause rip currents is explainable. But what caused the extreme shift in rip related wave directions from southwest in the years 2020 and 2022 to northwest in 2023 remains unclear. A reason for this could be the bathymetrical situation of the rips in which a change seems to be visible in the local situation, possibly in relation with a nourishment. The rips in 2023 look closed at the north side, resulting in an outflow more orientated towards the south, best activated by waves from the north. This is visualized in Figure 20 where the red arrows represent incoming waves when the bars are just submerged, and the blue arrows represent the outflow. it is difficult to draw conclusions since the category 1 dataset is small. The fact that ¾ of the rescues were on the same day makes the reliability of the numbers more questionable but also more interesting in how it will develop in the coming years. The rescue related wind angles (Figure 19b) are a lot more diverse and thereby strongly suggest having less impact on the actual development of rip currents, although the wind is rarely blowing in the opposite direction of the waves.

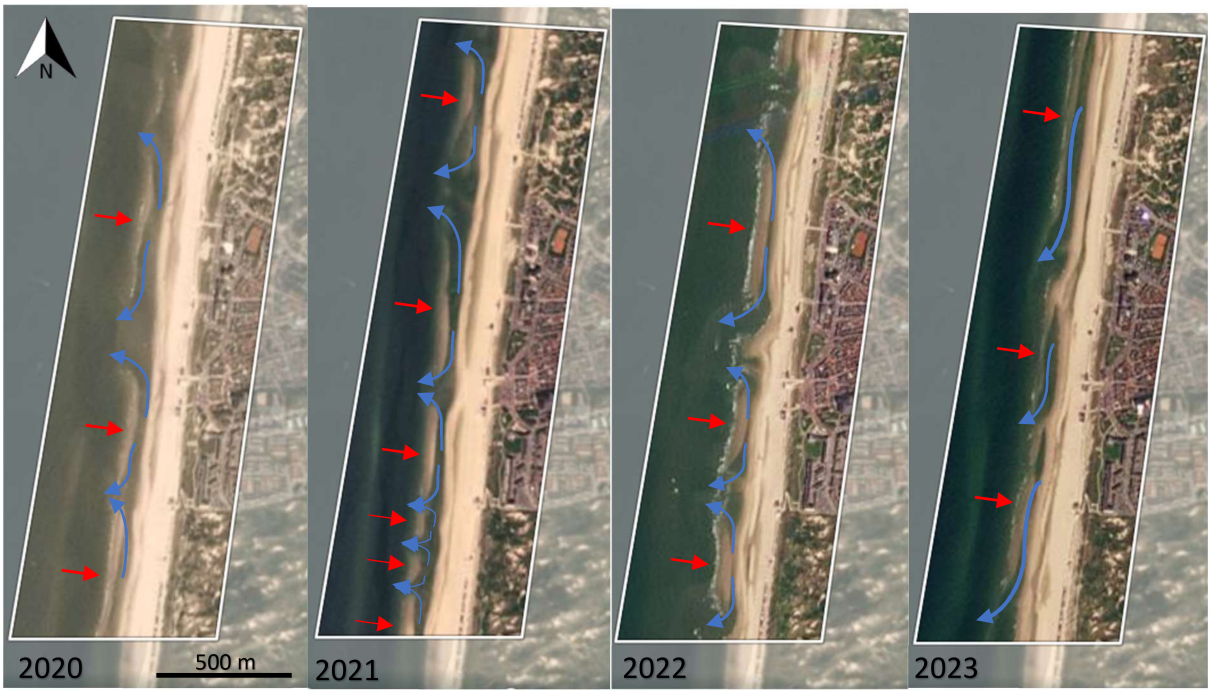


Figure 20 – Bar development of the Egmond coastline, possibly explaining the change in dominant wave direction, from 2020 to 2023.

The wave height also showed a difference over the three locations (Figure 21). The peak in Egmond on this parameter was early in the wave range (around 60cm) in comparison with The Hague (wide range around 120cm) and Monster (around 100cm). The late peak in the The Hague data at 210cm is mainly caused by the extraordinary day with 10 rescues. A reason for the differences in wave height can be the relatively low dominant waves in Egmond that originate from the south, these local wind generated waves are mainly formed after The Channel and smaller because of the short fetch. The low wave dominance of southern waves in Egmond is also visible in the wave roses presented in Section 4.1.

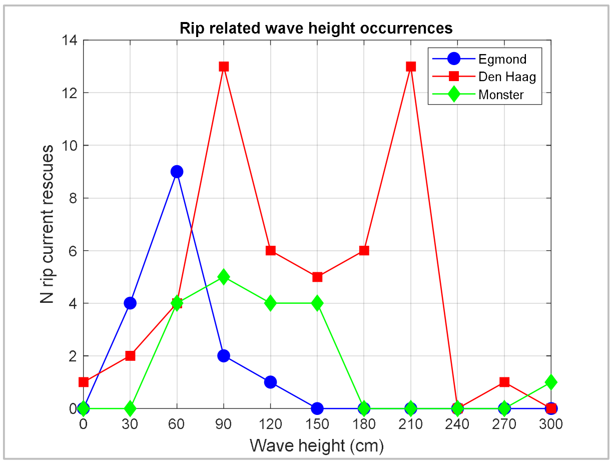


Figure 21 - Rip current related wave heights over the different study sites.

5.2. Influence of probable and possible rip related rescues

Due to the uncertainty in rip current identification, it is interesting to look at the distributions of different rescue categories within a specific environmental parameter. This to determine the probability of the real number of rip related rescues, now named as category 1 rescues, being larger. The wave direction and water height both showed a clear relation with category 1 rescues (Chapter 4), these parameters are therefore compared for the different categories. As explained in Chapter 3.3.1 category 1 is certainly rip current related, category 2 probably and category 3 possibly.

In Egmond most of the added category 3 rescues are with waves from the north/northwest (Figure 22a). In the category 1 data a clear shift was obtained in the wave angle towards the north in 2023 (Section 4.1.). But only two of these added rescues with northern waves took place in 2023, possibly denoting that there were more rip related rescues with waves originating from the north, even before 2023. Still, no rescues occurred with shore normally incident waves and there were no outlying values in comparison with the cat. 1 rescues. The water height showed some additional rescues during higher tide (figure 22b), with category 1 rescues occurring mostly with low tide this slightly reduces the chance of those rescues being rip current related. The wave height and wave period neither showed any major differences (Appendix J1). Overall, there are quite a few differences between cat.3 and cat.1 data, making their relation to rips questionable. Nevertheless, since the decent number of similarities in the data as well, the real number of rip current related rescues (cat. 1) is likely to be higher. As mentioned in Section 3.2 a view days where missing data. This is causing the missing wave angle of the category 2 rescue on 08-07-2020.

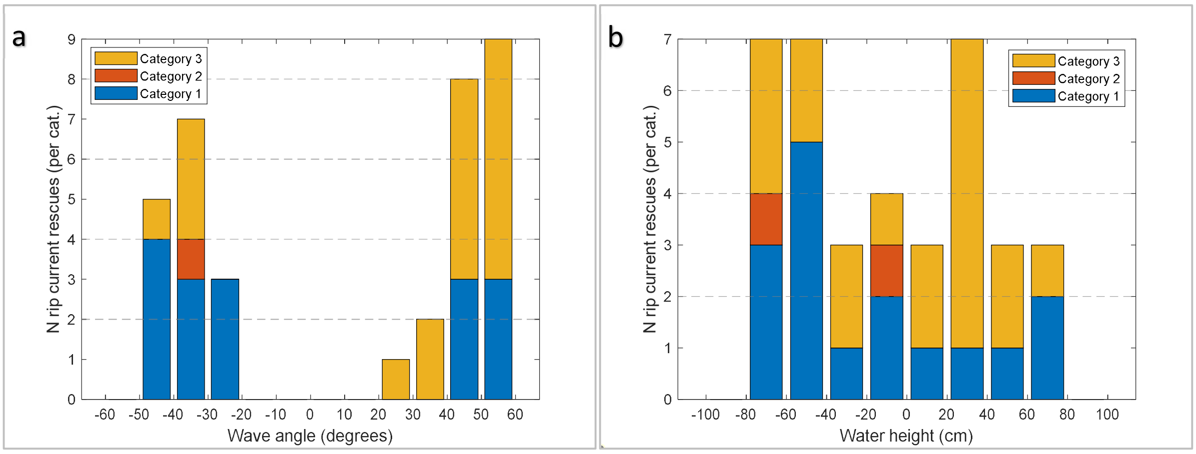


Figure 22 a & b – Different rip current probabilities Egmond, Wave angle (a) and Water height (b)

For The Hague, the extra rescue data broadly resembles the category 1 rescue data, although there are a few differences. For the wave angle the peak in extra data layed around the southwest (-60 deg.) which is surprising, given the category 1 relation to waves from the North (around 50 deg.)(Figure 23a). For the water height the added rip categories are remarkably evenly distributed over the values, both positive and negative (Figure 23b). Again, slightly contrasting to category 1 data, which clearly showed a peak around -40cm. Purely looking at these parameters it is quite likely that not all added rescues were be rip related. Nevertheless, since there are quite some similarities as well, the real number of rescues that should be indicated as category 1 is likely to be higher.

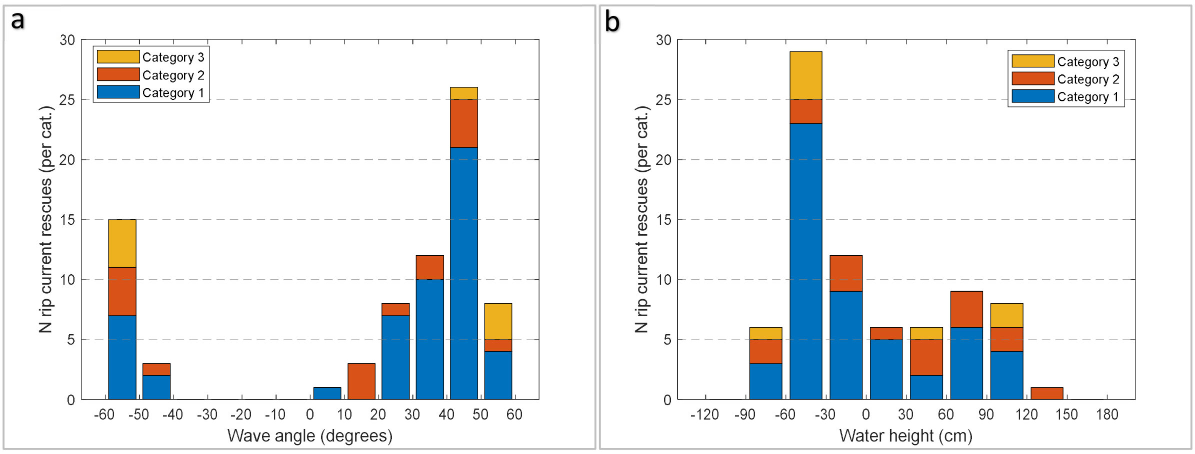


Figure 23 a & b – Different rip current probabilities The Hague, Wave angle (a) and Water height (b)

In Monster there were a lot of category 3 rescues due to unclear descriptions as explained in Section 4.3. Within the wave angle, the extra data does not show any new values. The peak is orientated a fraction more to the west, with also more rescues being related to southwestern waves, just like The Hague (Figure 24a). The water height showed a few high water related rescues, contrasting the category 1 trend (Figure 24b). Still the peak in added data clearly lays between -60 and -40 cm. Unlike Egmond and The Hague, the wave period in Monster showed some cases with a larger wave period than the category 1 rescues, enlarging the rip relation chance (Appendix J3). In comparison with the other study sites the amount of extra data that coincided with the category 1 data is higher. This indicates that the real number of rip related rescues in Monster is very likely to be higher.

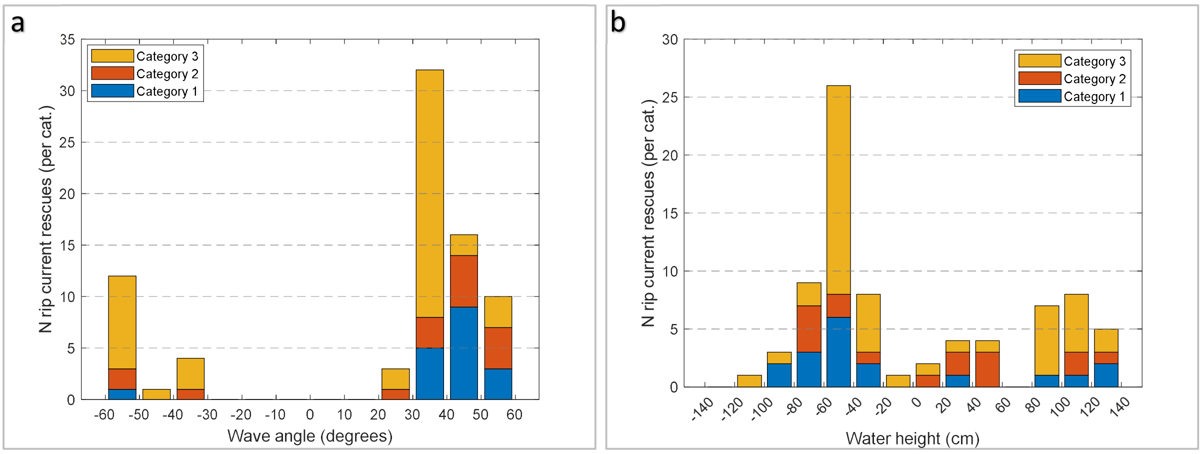


Figure 24 a & b – Different rip current probabilities Monster, Wave angle (a) and Water height (b)

5.3. Correlation between parameters

A small side study looked at the correlation among the environmental parameters that are covered in this research, during rip current related rescues in The Hague (Figure 25). By also including a correlation matrix on the whole 4-year period (figure 26) the differences between overall correlations and those specific to rip current related incidents can be investigated. In these figures the Pearsons correlations coefficient I is given for the different parameters. An ‘1’ represents a strong positive relation between the parameters, ‘-1’ a strong negative correlation and ‘0’ means no mathematical relation between the two.

For the category 1 rip related rescues the matrix shows a strong correlation between wind and wave direction (R = 0.76). In the results in Chapter 4, it became clear that the wind direction fluctuates more than the waves between north and southwest. Still, because the wind is rarely aimed in the opposite direction from the waves and on days with multiple rescues often in the same positive direction the correlation is high. Additionally, the wave period shows a (weak) positive correlation with wind angle (R = 0.43), wave angle (R = 0.28) and wave height (0.42). Plausibly, according to this data, rips are activated by larger swell waves with extended periods tended to originate from the north(east), especially with winds from the same direction. Finally, the cat. 1 matrix shows that a higher wind speed corresponds with a lower wave period, expressed by a negative correlation. This is a surprising outcome since generally stronger winds mean higher waves with longer periods. A possible reason is the focus on rip current related rescues. With strong winds most people are not swimming and therefore not rescued. With low wind speeds people do go into the water and if rips are activated during calm conditions, it is by long period swell waves.

In terms of weather parameters, the correlations are weaker. There is a weak positive correlation between sunshine and temperature (R = 0.22), aligning with the common observations that it is often warmer during sunny days. The relationships involving ‘rain’ are difficult to interpret, since n = 1 for rainy days. However, the negative correlation with temperature (R = -0.26) and sunshine (R = -0.36) seems to be right although the sunshine-rain link was expected to be near -1. The wind speed is overall higher with bad weather and especially rain (R = 0.36).

The correlation matrix over the total 4-year dataset shows a lot of weaker correlations. Only the wind angle – wave angle (R = 0,68) and sunshine – temperature (R = 0.37) maintained a decent correlation. The notable correlations between wave period with the wind angle (R = 0.01), wave angle (R = 0.11) and wave height (R = 0.04) decreased a lot. This suggests that the collaboration between these factors is especially important for the existence and danger of rip currents. Notably, in contradiction to the category 1 rescues the 4-year dataset showed a positive correlation between wind speed and wave period of R = 0.28. This confirms the aforementioned theory, that by focussing on rip currents swell waves are over-represented and therefor give a negative correlation. Looking at the 4-year average swell waves are less dominant and therefore the expected correlation is obtained: strong wind means higher waves, means longer wave periods.

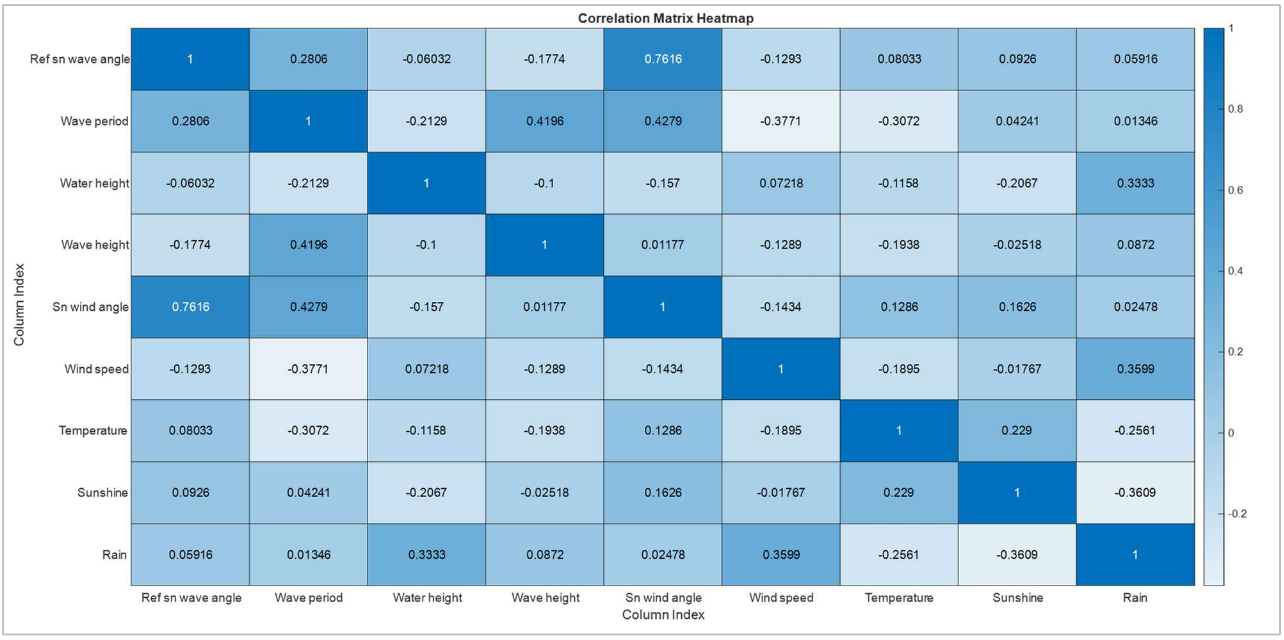


Figure 25 – Correlation matrix environmental parameters The Hague, rip current related.

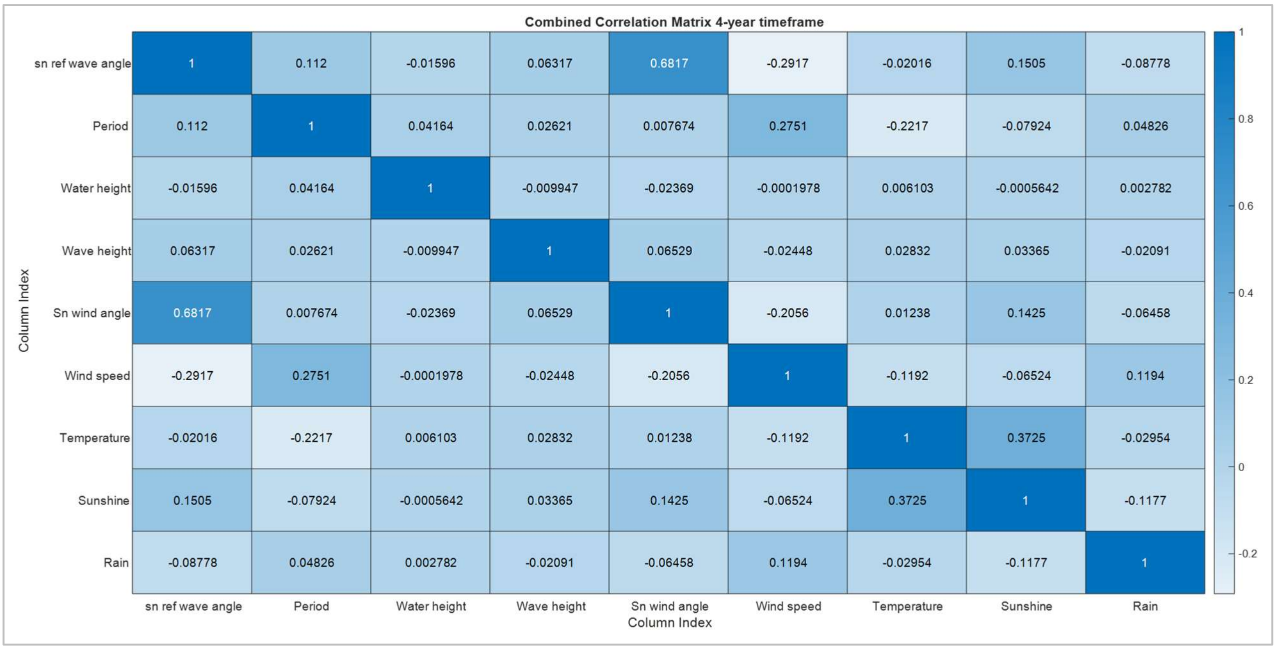


Figure 26 – Correlation matrix environmental parameters The Hague, total four-year dataset.

5.4. Comparison with earlier research

The best comparison of this research can be made with de Zeeuw (2011), conducted on Scheveningen beach in The Hague. The research of de Zeeuw had a broader focus on currents in general but there are still some relevant results in conditions and locations for rip related rescues. Besides this research conducted in the Netherlands a comparison with other studies around the world is also interesting, to see what the similarities and differences are between wind-wave and swell dominated coastlines.

The first relevant condition given in the research of de Zeeuw is: "*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)*". Due to limited groyne information and a scarcity of rescues during winds from the (south)west that part can neither be confirmed nor denied. The rest of the theorem indeed seems to apply. Oblique onshore winds are overall stronger than side shore winds (Figure 27). A sidenote here is that oblique onshore winds did overall occur more often over the 4-year dataset, also with moderate strengths. When taking the condition from de Zeeuw as truth it would suggest that most of the rescues at The Hague were boundary controlled, since most rescues occurred with strong oblique onshore winds near 5 bft (8.0 – 10.7m/s).

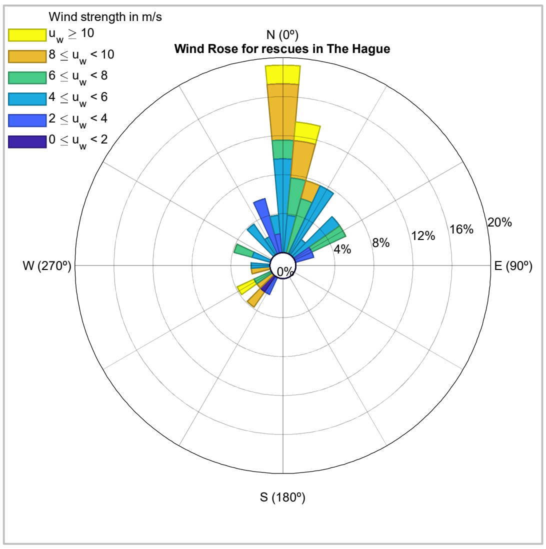


Figure 27 - Wind rose rip related rescues in The Hague, figure from own research.

About open beach rip currents the research said, "*most rip related rescues were performed during (near) normally incident, longer period waves (<15 degree angle) and mild offshore wind conditions*." This is not in line with our research results as there are almost no rip rescues with normally incident waves (predominantly 30 – 50°) and in the few cases it happened, it was with a low wave period (Figure 28). Also, the rescues do not coincide with offshore winds. If we strictly follow this verdict about open beach rip currents, the contradiction would mean that during this 4-year period hardly any open beach currents occurred. Unless the local bathymetrical situation changed since their research in 2011 or open beach rip current were not recognised as rip current by the lifeguards since they are less common and more difficult to spot. Nevertheless, the assumption of most dangerous rip currents being boundary controlled corresponds with the previous condition.

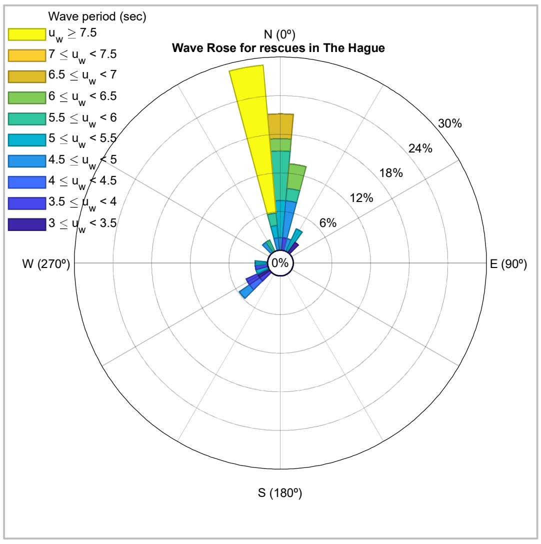


Figure 28 - Wave rose rip related rescues in The Hague, figure from own research.

Worldwide most of the researched beaches are swell dominated like mentioned earlier, this influences the critical conditions for rip current activity. Research in southwest France showed that rip current drownings mainly occurred near neap low tide, under shore normal incident waves, average to above average wave height (2m) and period (10sec) (*Castelle et al., 2020*). This is slightly different than the research conducted in Great Brittain, stating that High-risk, high-exposure scenarios for bathers were also shown to occur around mean low water and a peak wave period (>10 sec), but under small swell wave conditions with a significant wave height (Hs < 1 m) (Scott et al., 2014). In Costa Rica a research was done about rip current related wave heigh and period along both the Pacific coast (Hs≈1.5m & Tp≈14s), as the Caribbean coast (Hs ≈ 1.75m & Tp ≈ 8.5sec) (Arozarena et al., 2015). These results show that the predominant wave period abroad is higher than the Dutch studies. This emphasizes the main difference between wind-wave and swell coastlines, the larger period of swell waves. The shore normal incident wave dominance in France and Great Britain is another major difference, because for the Netherlands this was mainly oblique. For Costa Rica the wave dominance is not mentioned in the research. The wave height is in the same order of magnitude, also the water height is in all studies mainly below 0, matching with the results along the Dutch coast.

De Zeeuw his conclusions on temperature closely align with the outcomes of this thesis. Both studies highlight that rescues most often occur with air temperatures primarily between 19 and 25 degrees. Finally, it was noted that "The *number of rescues per day of the week is relative evenly distributed, although a peak is visible on Saturday and a dip on Monday*." Due to the extraordinary day with 10 rescues the peak in this research falls on a Thursday, followed by Saturday and Sunday. The dip falls on a Wednesday followed by Monday. Except for the extreme peak, rescues are in general evenly distributed over the weekdays, see Figure 29. So, these results do correspond quite well.

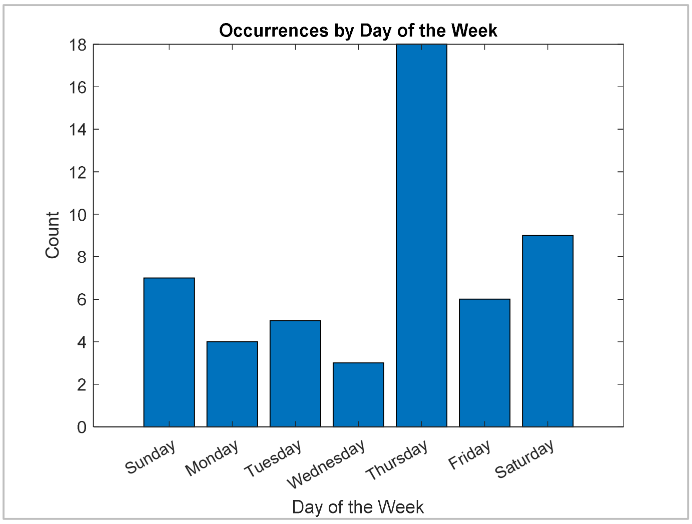


Figure 29 – Rip related rescue distribution over the weekdays The Hague

5.5. Human behaviour

Apart from the physical factors in rip related rescues, a lot has to do with human behaviour. It is important to recognise that the absence of rip related rescues with temperatures below 17 degrees Celsius does not necessarily mean that there were no rips. Rather, that most people do not like to swim with these temperatures. The same goes for weather-related parameters such as rain, sunshine and windspeed. Besides these obvious parameters, the wave height also plays a role. The trough of a rip is deeper than the surrounding seabed, providing the illusion of calmer and saver waters, without breaking waves (*Leatherman et al., 2003*). Unaware swimmers looking for calmer water might get themselves in trouble by stepping into a calmer seeming rip current.

Beyond the parameters extensively covered in this thesis, there is also the location and local situation of the beach and surf zone that matter. Looking at pictures and satellite data, it seems that people stay relatively close to the beach access paths or beach restaurants and not walk much further alongshore. Additionally, while looking for a spot to spend the day, people often do not look at the bar and rip situation in the surf zone. So, if by any chance there is a rip current active directly in front of a dune crossing, it is likely that rescues will be needed that day. Especially because, as mentioned in Section 2.4, the overall awareness about rip currents (*Uebelhoer et all., 2022*) and the ability to spot rip currents on site (*Pitman et al., 2021*) is still low, just like the knowledge about the warning flag system (*Roefs et al., 2023*).

The high number of factors influencing rip current danger not only complicates research but also makes it difficult to improve the beach safety. Increasing the beach safety requires raising awareness among beachgoers about the dangers in such a way that they want to change their beach behaviour. A notable example is a study in Australia that looked at the influence of the tv show Bondi Rescue based on lifeguards at Bondi beach. 1852 global viewers filled in a survey afterwards where 78% of the respondents felt that the show improved their beach safety knowledge significantly (*Warton et all., 2017*). This shows that we should not only think about the regular form of education, but also think outside the box.

5.6. Recommendations

During the research several bottlenecks and ideas to increase the quality and functionality of the safety system came up. These ideas on how to move on will be evaluated in this chapter.

5.6.1. Unambiguous rescue notation

In this research, there were some variables that hindered the execution of the project. The most crucial factor was the registration and description of rescues. The quality of notation was highly dependent on the year, location, and present lifeguards. Especially for research like this, a specific subject in swimming safety, an unambiguous open data source is particularly important. An option to do this, is the implementation of one lifeguard incident report along the whole Dutch coast. An example has been added in 'Appendix K – Lifeguard incident report'. This report is now used in France and significantly improves the unambiguity by just ticking off boxes (*Castelle et al., 2018*). By adding an extra box 'in case of swimmer incident' with different potential causes like: 'longshore current', 'rip current', 'pounded in breaking zone' and 'stepped or bumped into something sharp', the quality of notation will increase a lot and with that, the quality of specific research. This can all be implemented into either a site or an app, whatever makes the use of it the easiest and most efficient.

5.6.2. Rip Dynamics

Focussing on rip current related rescues had the goal to immediately find out the total set of local parameters, important for rip current development and what made them dangerous for bathers. Unfortunately, the results are not as clear as hoped. The small quantity of locations and registered rip related rescues is one of the main problems. Therefore, I would recommend follow-up studies along the wind-sea dominated Dutch coast to get a better view on when and where rip currents appear. There are multiple research strategies to achieve this, such as drifters at a specific location. But because rip currents can appear along the whole coast, I would rather recommend investigating the possibilities of satellite, video, and citizen science (with the smartphone) data in localizing active rip currents, possibly with help of artificial intelligence. For Egmond it will be particularly interesting to see the development in bar patterns and dominant rip rescue wave angle, and to investigate how the sudden shift between 2022 and 2023 could occur.

5.6.3. Creating awareness

The most important thing is to prevent people from being put in danger. To do this the right way, a few questions can be asked: who are the people get into trouble? Where are the people on the beach in relation to rip currents and does the warning flag system work? For the latter it was already mentioned that there is a lack of knowledge in the exact meaning of the flags (*Roefs et al., 2023*), but a lot of these details are still unknown or barely investigated for the Dutch coast.

A good place to start an awareness project are the schools. If children learn about the fun but also the dangers of the sea, and the meaning of warning flags from an early age, they will benefit from it for the rest of their lives. Besides children, it is also important to somehow bring the information to grownups, for example in a short tv or social media commercial, a tv show (like mentioned in Section 5.5) and an user-friendly information website/app. To help with the understanding it might be useful to recognise different beach situations. The "beach rip current hazard assessment" of Scott et al (2022) can be used for this (Appendix L – Rip current assessment*).* This assessment gives a clear overview of different beach types and sandbar situations, with the corresponding beach rip hazard. The providence of information on the location itself can also be a way of helping people to understand. On a few beaches in the Netherlands, they already have warning flags or (electronic) signs, especially for rip currents. These examples are added in 'Appendix M – Rip current safety measures'. I will suggest to further improve this with the use of electronic screens that clearly shows the live situation of the beach and the possible dangers. This can even be more improved with a user-friendly app which you can look at on the way to the beach or at home, to see the current situation on your favourite beach. Scott et al (2022) already investigated this option and came up with a design, added as 'Appendix N – Safety design'. This design shows every essential element of the local beach situation, from weather to currents and other dangers.

6. Conclusion

This research aimed to address the following main question: '**Under what circumstances do rip currents pose the greatest threat for bathers along the Dutch coast?'**. By using weather, water, and rescue data over a 4-year timeframe a quantitative research has been carried out, in which several key findings emerged.

Regarding the available rescue data, it is not totally suitable yet to determine whether a rescue is rip current related or not, resulting in a lot of category 3 rescues. Environmental parameters during the rescues are really fluctuating while the rips itself were a lot more stable according to the satellite images and were often clearly visible.

There is no straightforward answer on when rip current related rescues occur since it is highly dependent on the location and associated variables. However, there is a global common threat. According to the results, rip currents along the Dutch coast only occurred under obliquely incident waves with an angle higher than 20° relative to shore normal and water levels most often below NAP. The wind direction showed less of a specific trend but is rarely directed straight offshore (>120° SN) and blowed, in the high rescue events, always in the same direction as the waves. The main differences between the locations are attributed to the orientation of the coastline with respect to the North. Egmond is oriented relatively far to the north with a small eastward angle of seven degrees, where The Hague and Monster lie in a 48 degrees eastward angle. As a result, rip currents in Monster and The Hague are associated with higher waves (around 120 cm) from the north and Egmond with more average wave heights (around 60cm) from both the north and south.

Furthermore, according to the weather data, only one rip related rescue was conducted during rainfall over the whole four-year dataset and in by far most of the cases it was fully sunny. Temperatures were mainly between 18 and 24 degrees, contrasting with the overall average temperature range between 6 and 18 degrees. Exceptional days with three or more rip related rescues often coincided with high temperatures (>18), a lot of sun (>8), moderate to long period waves (4 – 8 sec) and winds from the North. However, not all high rescue days showed such clear values.

Working with only rescue related data highly narrows the scope on rip currents. To make this really succeed a better registration system and more research into the presence and activeness of rip currents along wind-sea dominated coastlines is necessary. Besides, a program to increase knowledge and awareness about the dangers of the currents is recommended for all ages.

Sources

Aagaard, T., Greenwood, B., & Nielsen, J. (1997). Mean currents and sediment transport in a rip channel. Marine Geology, 140(1-2), 25-45. https://doi.org/10.1016/S0025-3227(97)00025-X

Austin, M., Scott, T., Brown, J., Brown, J., MacMahan, J., Masselink, G., & Russell, P. (2010). Temporal observations of rip current circulation on a macro-tidal beach. Continental Shelf Research, 30(9), 1149-1165. https://doi.org/10.1016/j.csr.2010.03.005

Arozarena, I., Houser, C., Echeverria, A. G., & Brannstrom, C. (2015). The rip current hazard in Costa Rica. Natural Hazards, 77, 753-768. https://doi.org/10.1007/s11069-015-1626-9

Borgonovi, F., H. Seitz and I. Vogel (2022), "Swimming skills around the world: Evidence on inequalities in life skills across and within countries", OECD Social, Employment and Migration Working Papers, No. 281, OECD Publishing, Paris, https://doi.org/10.1787/0c2c8862-en

Bosboom, J., Stive, M. (2023), Coastal dynamics (pp 189 – 191). https://doi.org/10.5074/T.2021.001

Bowen, A. J., Rip currents, 1, Theoretical investigations, J. Geophys. Res., 74(23), 5467- 5478, 1969. https://doi.org/10.1029/JC074i023p05467

Brander, R. W., Bradstreet, A., Sherker, S., & MacMahan, J. (2011). Responses of swimmers caught in rip currents: Perspectives on mitigating the global rip current hazard. International Journal of Aquatic Research and Education, 5(4), 11. https://doi.org/10.25035/ijare.05.04.11

Brander, R. W., & MacMahan, J. H. (2011). Future challenges for rip current research and outreach. Rip Currents, Beach Safety, Physical Oceanography and Wave Modeling, edited by: Leatherman, S. and Fletemeyer, J., CRC Press, Boca Raton, FL, 1-29.

Castelle, B., Brander, R., Tellier, E. et al. Surf zone hazards and injuries on beaches in SW France. Nat Hazards 93, 1317–1335 (2018). https://doi.org/10.1007/s11069-018-3354-4

Castelle, B., Scott, T., Brander, R. W., & McCarroll, R. J. (2016). Rip current types, circulation and hazard. Earth-Science Reviews, 163, 1-21. https://doi.org/10.1016/j.earscirev.2016.09.008

Castelle, B., Scott, T., Brander, R., McCarroll, R. J., Tellier, E., de Korte, E., … & Salmi, L. R. (2020). Wave and tide controls on RIP current activity and drowning incidents in Southwest France. Journal of Coastal Research, 95(SI), 769-774. https://doi.org/10.2112/SI95-150.1

Dalrymple, R. A., MacMahan, J. H., Reniers, A. J., & Nelko, V. (2011). Rip currents. Annual Review of Fluid Mechanics, 43, 551-581. https://doi.org/10.1146/annurev-fluid-122109-160733

De Zeeuw, R. C. (2011). Nearshore currents and swimmer safety in the Netherlands. http://resolver.tudelft.nl/uuid:d1a39fb7-ecb7-4bde-b73e-b70f0d96a147

Engle, J. (2002). Formulation of a Rip Current Predictive Index Using Rescue Data Jason Engle*, James MacMahan, Robert J. Thieke, Daniel M Hanes and Robert G Dean* Graduate Assistant, Department of Civil and Coastal Engineering, University of Florida. Florida Shore & Beach Preservation Association, Citeseer (Vol. 285).

Feddersen, Falk. "The generation of surfzone eddies in a strong alongshore current." Journal of Physical Oceanography 44.2 (2014): 600-617. https://doi.org/10.1175/JPO-D-13-051.1

Gamito, M. N., & Musgrave, F. K. (2002). An accurate model of wave refraction over shallow water. Computers & Graphics, 26(2), 291-307. https://doi.org/10.1016/S0097-8493(01)00181-9

Hanes, D. M. (2016). Human instability related to drowning risk in surf zones for novice beachgoers or weak swimmers. Natural hazards, 83, 761-766. https://doi.org/10.1007/s11069-016-2337-6

Huisman, B. J., Walstra, D. J. R., Radermacher, M., de Schipper, M. A., & Ruessink, B. G. (2019). Observations and modelling of shoreface nourishment behaviour. Journal of Marine Science and Engineering, 7(3), 59. https://doi.org/10.3390/jmse7030059

Leatherman, S.P. (2013). Rip Currents. In: Finkl, C. (eds) Coastal Hazards. Coastal Research Library, vol 1000. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-5234-4_26

Li, Z., & Zhu, S. (2018). Why there are so many drowning accidents happened at Dadonghai beach, Hainan, China: Morphodynamic analysis. Journal of Coastal Research, (85), 741-745. https://doi.org/10.2112/SI85-149.1

MacMahan, J. H., Thornton, E. B., & Reniers, A. J. (2006). Rip current review. Coastal engineering, 53(2-3), 191-208. https://doi.org/10.1016/j.coastaleng.2005.10.009

McCool, J. P., Moran, K., Ameratunga, S., & Robinson, E. (2008). New Zealand beachgoers' swimming behaviours, swimming abilities, and perception of drowning risk. International Journal of Aquatic Research and Education, 2(1), 2. https://doi.org/10.25035/ijare.02.01.02

Miloshis, M., Stephenson, W.J. Rip current escape strategies: lessons for swimmers and coastal rescue authorities. Nat Hazards 59, 823–832 (2011). https://doi.org/10.1007/s11069-011-9798-4

Pattiaratchi, C., Olsson, D., Hetzel, Y., & Lowe, R. (2009). Wave-driven circulation patterns in the lee of groynes. Continental Shelf Research, 29(16), 1961-1974. https://doi.org/10.1016/j.csr.2009.04.011

Pitman, S. J., Thompson, K., Hart, D. E., Moran, K., Gallop, S. L., Brander, R. W., & Wooler, A. (2021). Beachgoers' ability to identify rip currents at a beach in situ. Natural hazards and earth system sciences, 21(1), 115-128. https://doi.org/10.5194/nhess-21-115-2021

Roefs, F. D., Hoogslag, M., & Olivers, C. N. (2023). Familiarity with beach warning flags in the Netherlands. Safety science, 158, 105952. https://doi.org/10.1016/j.ssci.2022.105952

Scott, T., Masselink, G., Austin, M. J., & Russell, P. (2014). Controls on macrotidal rip current circulation and hazard. Geomorphology, 214, 198-215. https://doi.org/10.1016/j.geomorph.2014.02.005

Scott, T., Austin, M., Masselink, G., & Russell, P. (2016). Dynamics of rip currents associated with groynes—field measurements, modelling and implications for beach safety. Coastal Engineering, 107, 53-69. https://doi.org/10.1016/j.coastaleng.2015.09.013

Scott, T., Masselink, G., Stokes, C., Poate, T., Wooler, A., & Instance, S. (2022). A 15-year partnership between UK coastal scientists and the international beach lifeguard community. Continental shelf research, 241, 104732. https://doi.org/10.1016/j.csr.2022.104732

Spydell, M., Feddersen, F., Guza, R. T., & Schmidt, W. E. (2007). Observing surf-zone dispersion with drifters. Journal of Physical Oceanography, 37(12), 2920-2939. https://doi.org/10.1175/2007JPO3580.1

Uebelhoer, L., Koon, W., Harley, M. D., Lawes, J. C., & Brander, R. W. (2022). Characteristics and beach safety knowledge of beachgoers on unpatrolled surf beaches in Australia. Natural hazards and earth system sciences, 22(3), 909-926. https://doi.org/10.5194/nhess-22-909-2022

Van der Zee, E. & Klomp, L., (2020) "Opleving en verval in Scheveningen", AGORA Magazine 36(1), pp. 38-41. Doi: https://doi.org/10.21825/agora.v36i1.16938

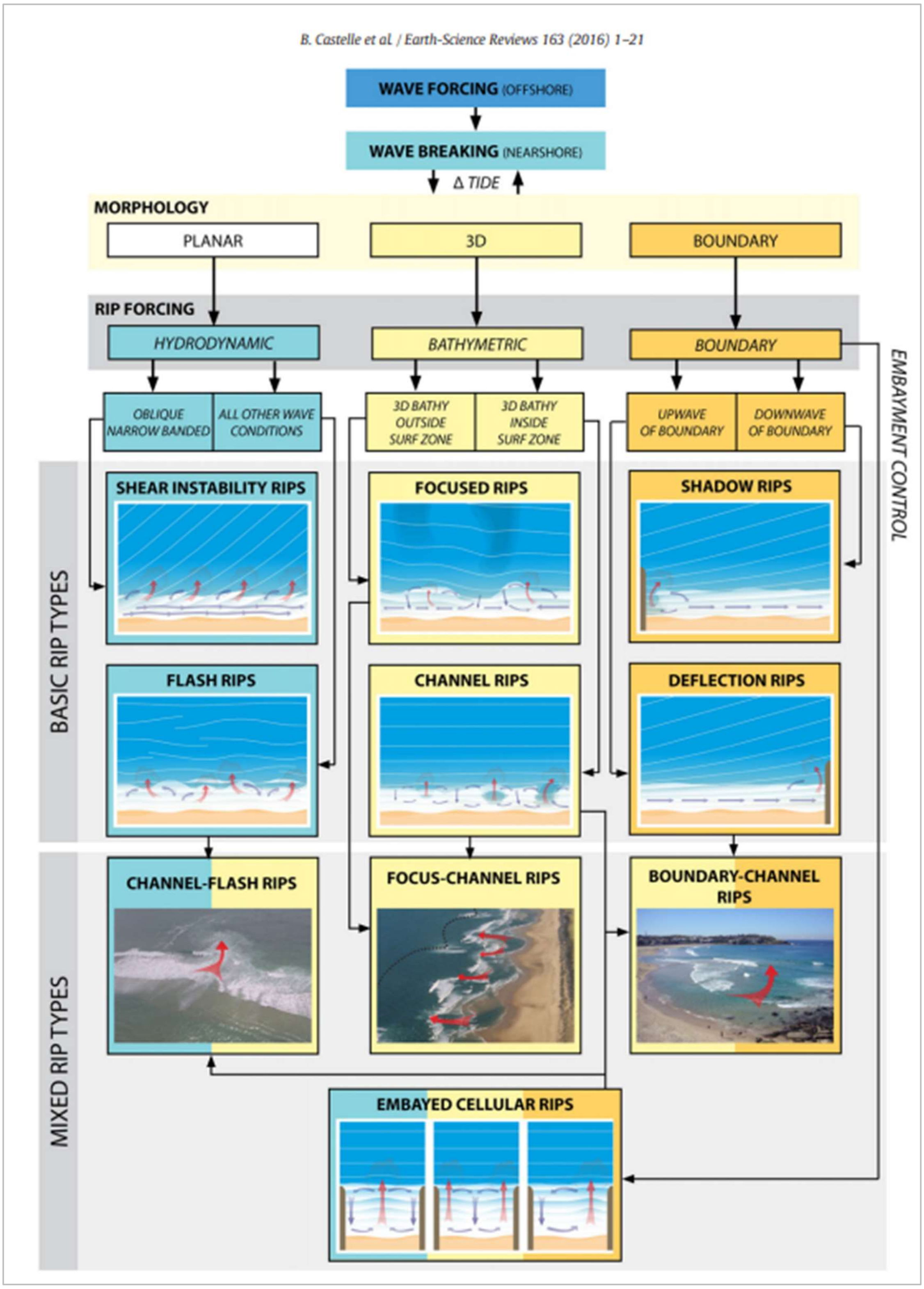
Warton, N. M., & Brander, R. W. (2017). Improving tourist beach safety awareness: The benefits of watching Bondi Rescue. Tourism Management, 63, 187-200. https://doi.org/10.1016/j.tourman.2017.06.017

Winter, G. (2012). Rip current characteristics at the dutch coast: Egmond aan Zee. http://resolver.tudelft.nl/uuid:639683cb-3ea9-42de-b57b-b63c05f36cfd

Winter, G., Van Dongeren, A. R., De Schipper, M. A., & de Vries, J. V. T. (2014). Rip currents under obliquely incident wind waves and tidal longshore currents. Coastal Engineering, 89, 106-119. https://doi.org/10.1016/j.coastaleng.2014.04.001

Appendices

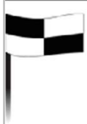
Appendix A- Distinct types of rip currents



The different rip current forcing mechanisms (source: Castelle et al., 2016)

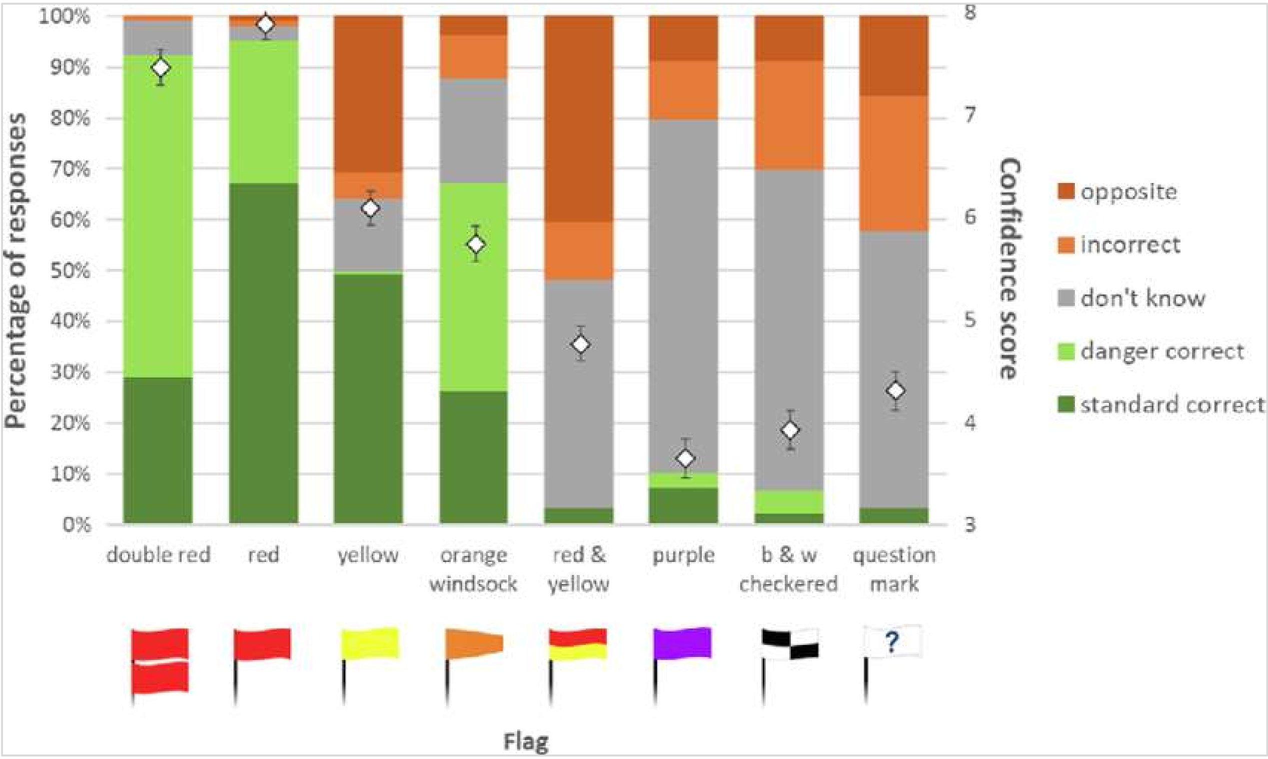
Appendix B – Warning flags and recognition

1.

Flag	Meaning (ILS[1])	Meaning (Dutch Royal Life Saving Federation[2])	Terms considered correct
 double red	Water closed to public use	Swimming and bathing prohibited! It's forbidden to enter the water. Doing so can result in a fine.	Forbidden, prohibited, fine (as in sanction)
 red	High hazard	Don't swim. Very dangerous! Serious danger. Swimming bathing or other water activities are strongly advised against.	Serious danger, very dangerous, not, strongly advised against / discouraged
yellow	Medium hazard	Beware when swimming! Dangerous! Danger. Swimming bathing or other water activities are advised against.	Danger, dangerous, pay attention, watch out, warning, caution, be careful, a bit dangerous, advised against / discouraged, rip current
 red & yellow	Recommended swimming area with lifeguard supervision	Lifeguards present! Rescue station is open and qualified lifeguards are on duty.	Lifeguards, swimming / bathing allowed / safe
 orange windsock	Offshore winds present, inflatables should not be used	Beware when swimming! No floating devices! Offshore winds. It is unsafe to use inflatables.	Wind, floating devices, inflatables
 purple	Marine pests present	Dangerous animals or pests in the water! Swimming is advised against.	Dangerous animals, pests, jellyfish, algae
 black & white checkered	Watercraft area	Water sports area! These flags indicate a water sports zone. Swimming is strongly advised against.	Water sports, boats
 question mark	n/a (not an ILS flag)	Lost child found! A lost child has been found and can be collected at the rescue station	Lost child, child found, report to rescue station

Meaning of different beach safety flags (Source: Roefs et al., 2023)

2.



Recognition of Dutch beach safety flags (Source: Roefs et al., 2023)

Appendix C- Field site situation

1. Egmond

(a) 18-07-2020, (b) 08-06-2021, (c) 28-06-2022 and (d) 20-05-2023
Source: Planet.com

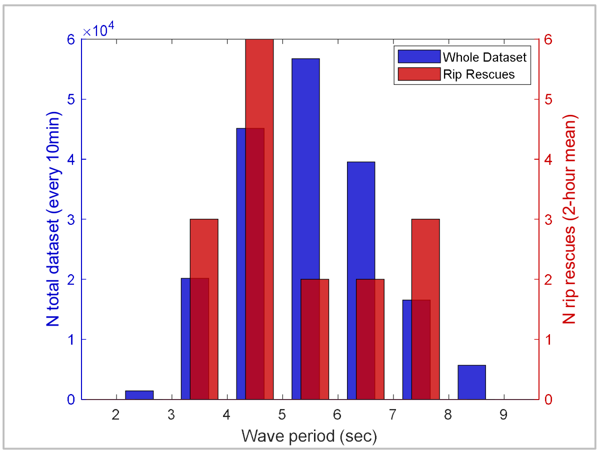
2. The Hague

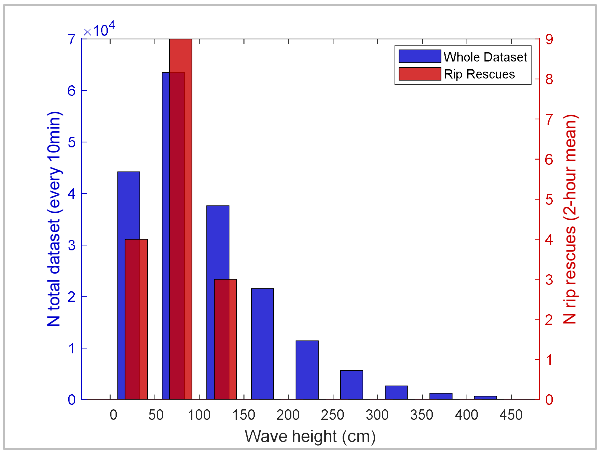
(a) 23-06-2020, (b) 10-06-2021, (c) 15-05-2022 and (d) 04-06-2023
Source: planet.com

3. Monster

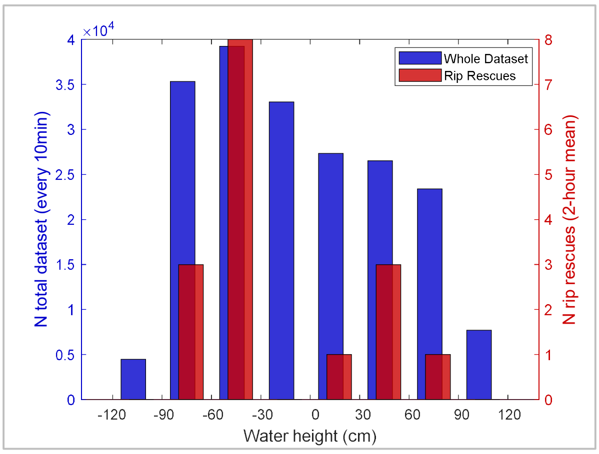
(a) 23-06-2020, (b) 08-06-2021, (c) 15-05-2022 and (d) 16-06-2023
Source: planet.com

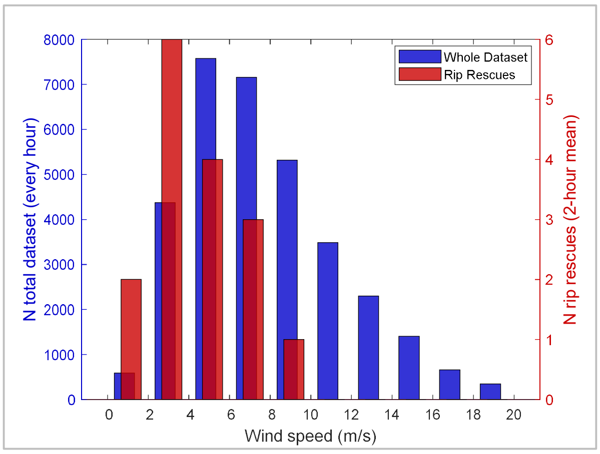
Appendix D – Figures Egmond



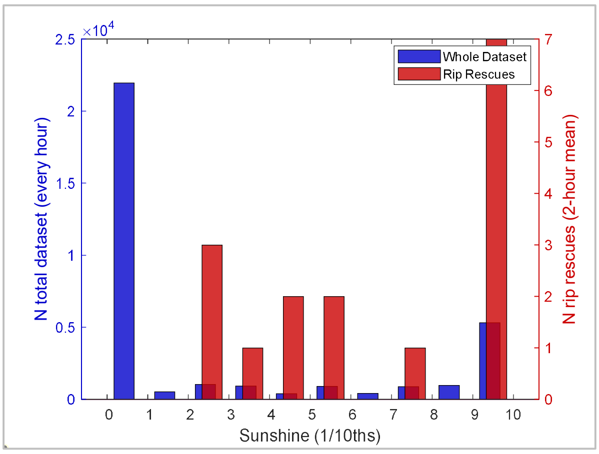


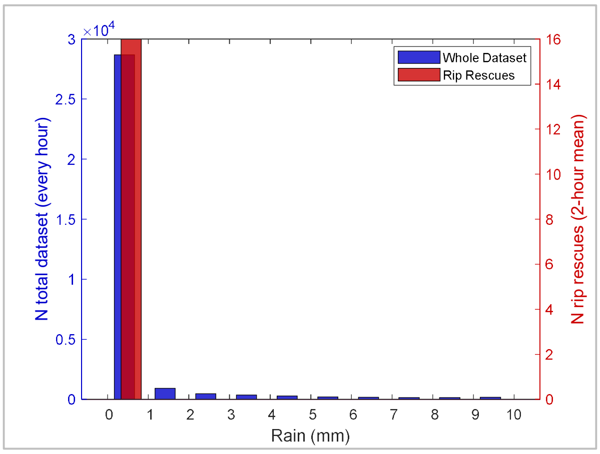
Total dataset vs rip current related Wave period and wave height





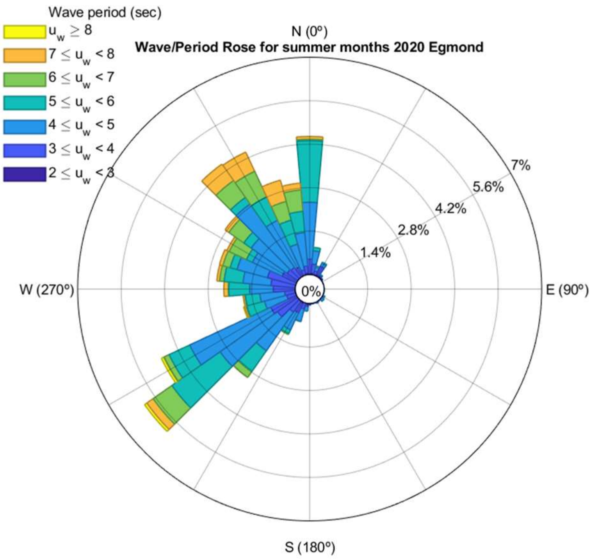
Total dataset vs rip current related water height and wind speed

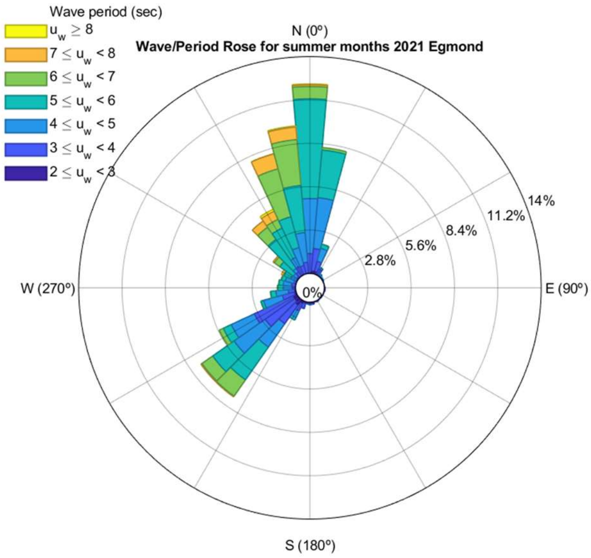


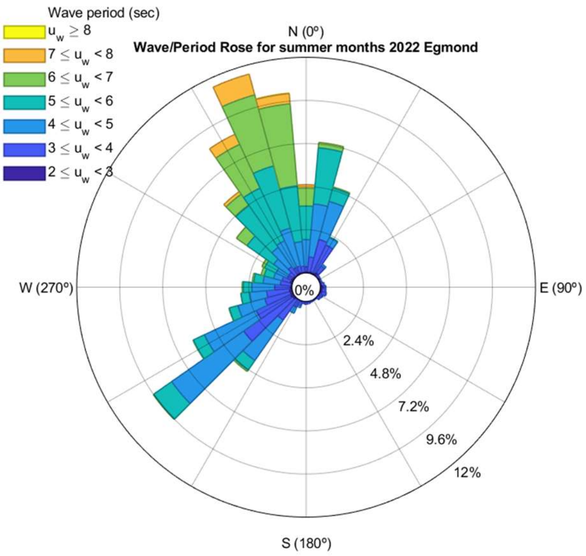


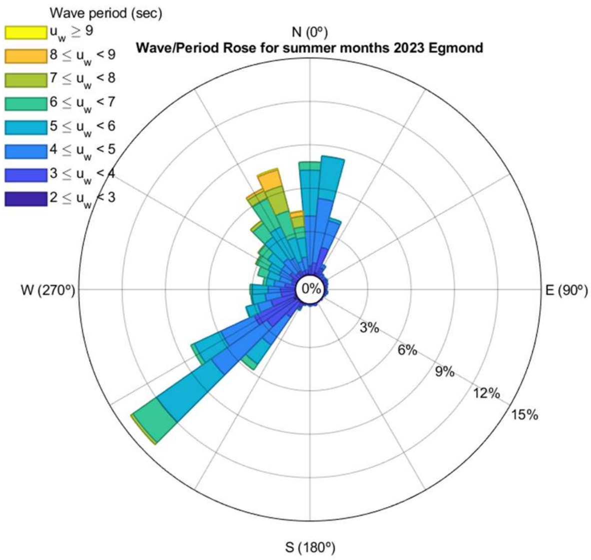
Total dataset vs rip current related sunshine and rainfall

Appendix E – wave roses Egmond (direction / period)

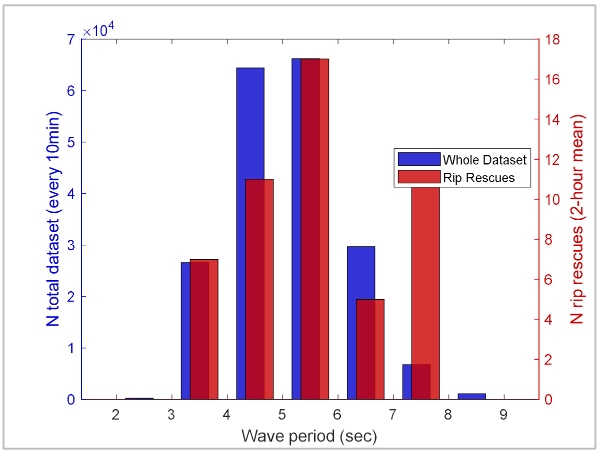


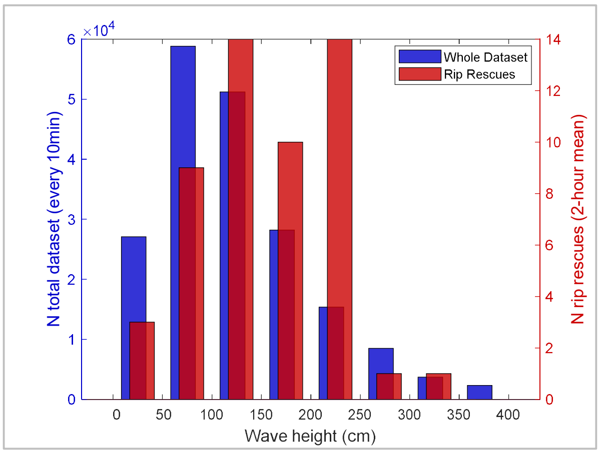




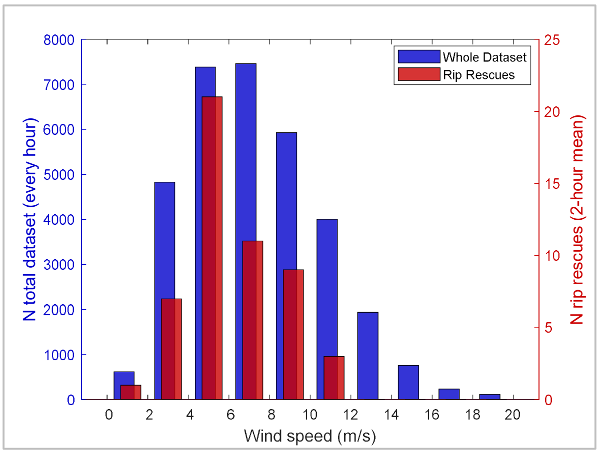


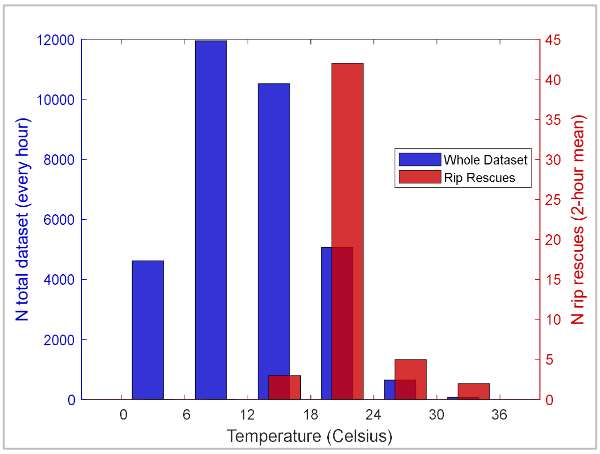
Appendix F – Figures The Hague



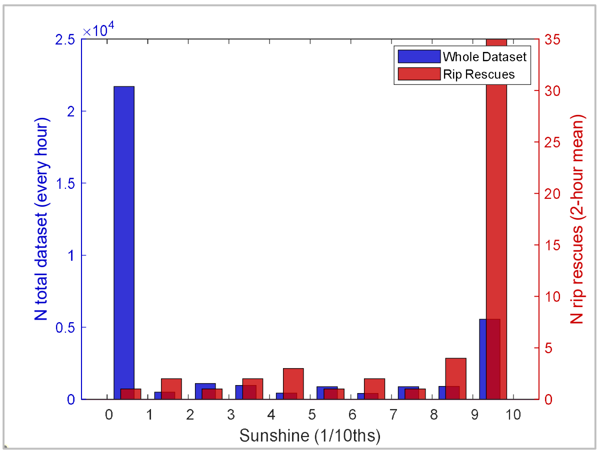


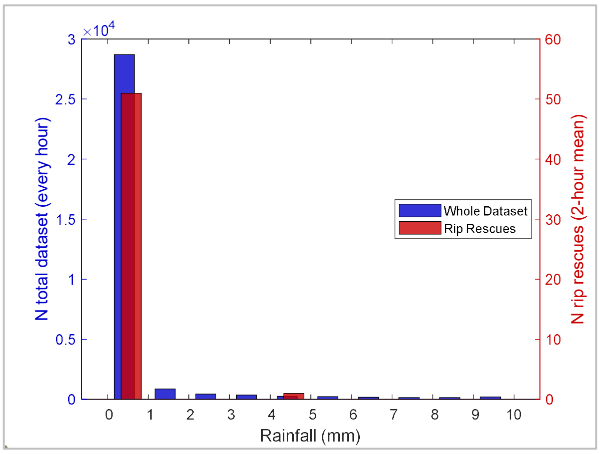
Total dataset vs rip current related wave period and wave height





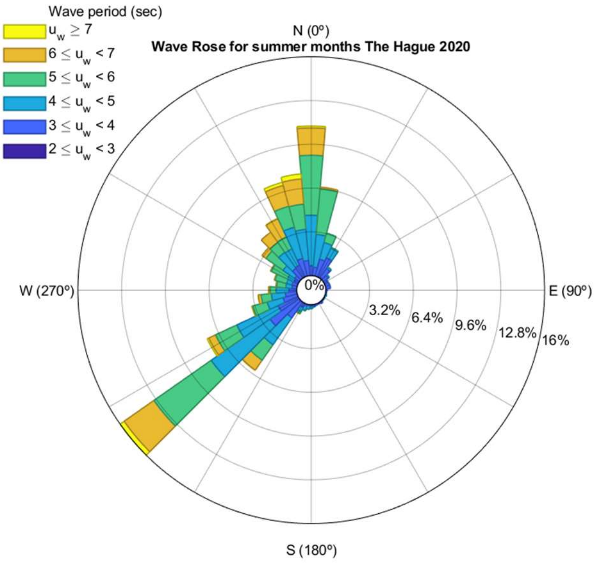
Total dataset vs rip current related wind speed and temperature

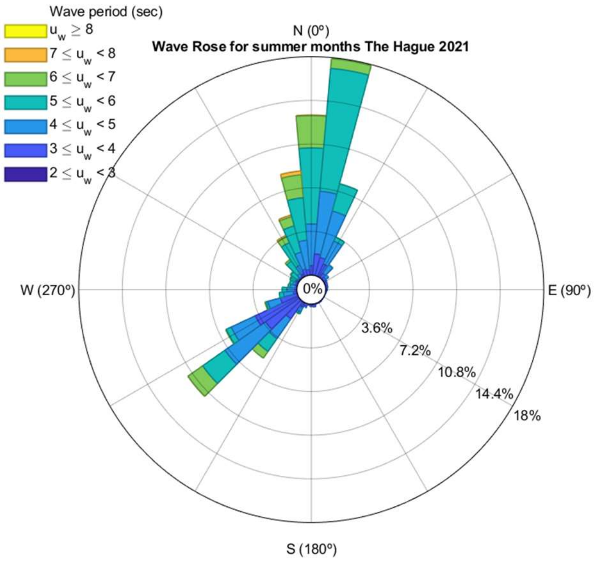


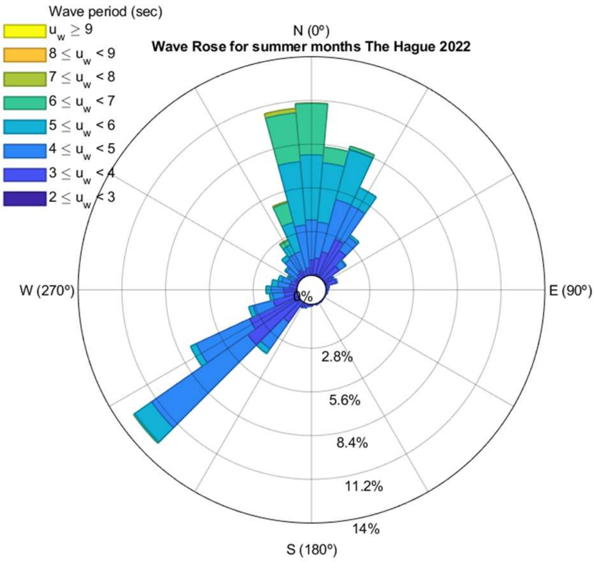


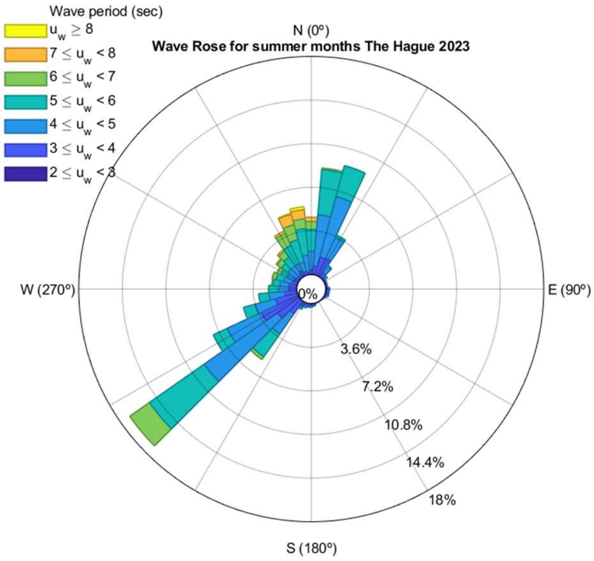
Total dataset vs rip current related sunshine and rainfall

Appendix G - Wave roses The Hague / Monster (direction / period)

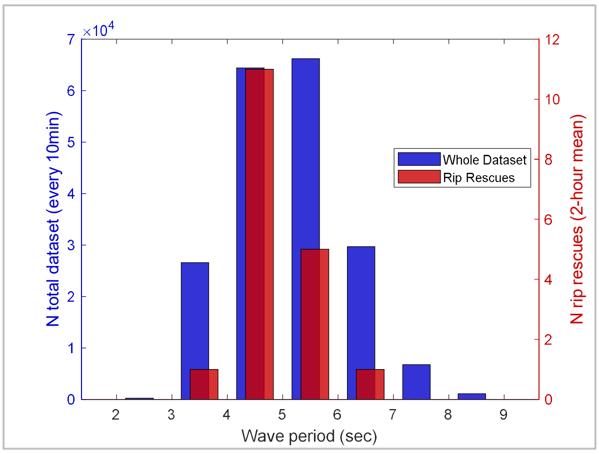


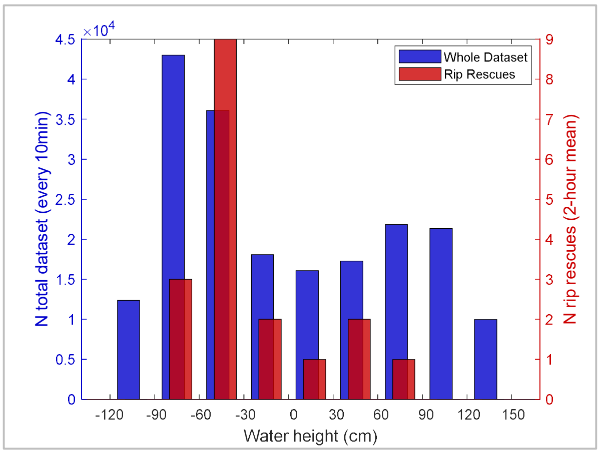




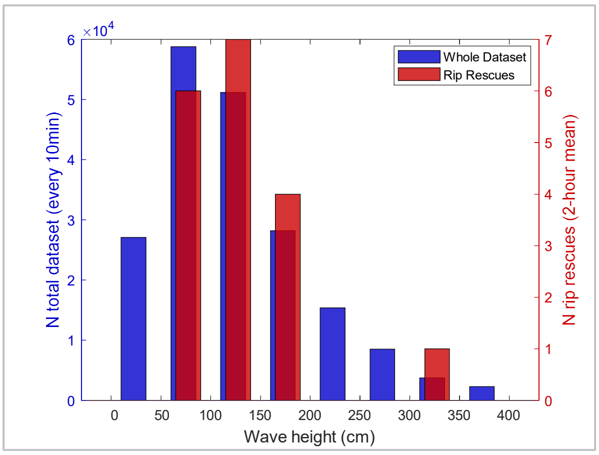


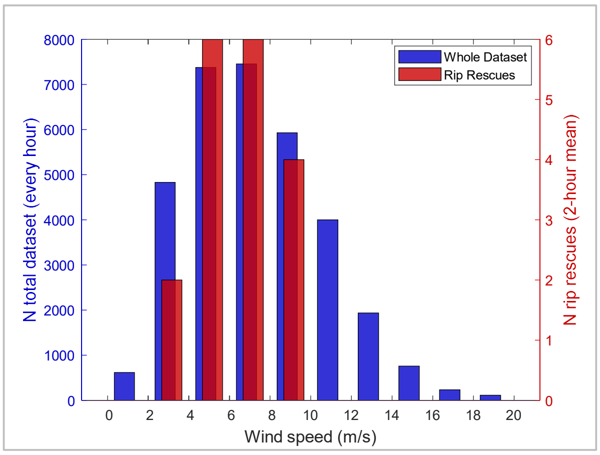
Appendix H – Figures Monster



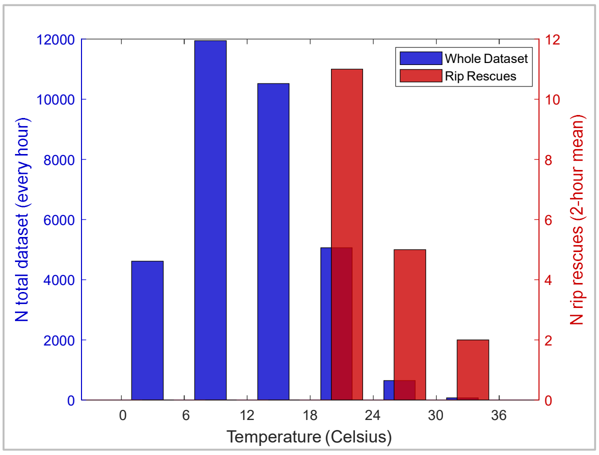


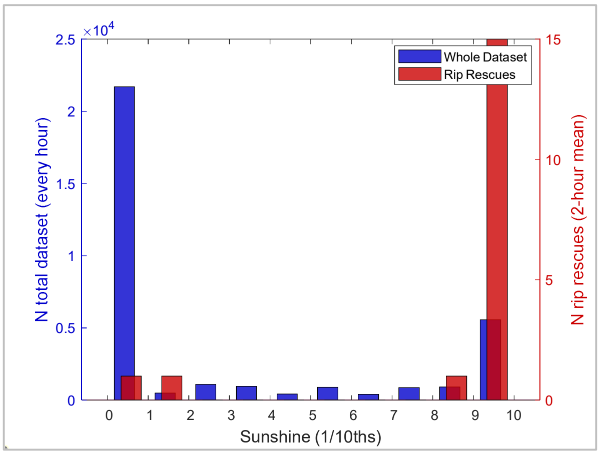
Total dataset vs rip current related wave period and water height



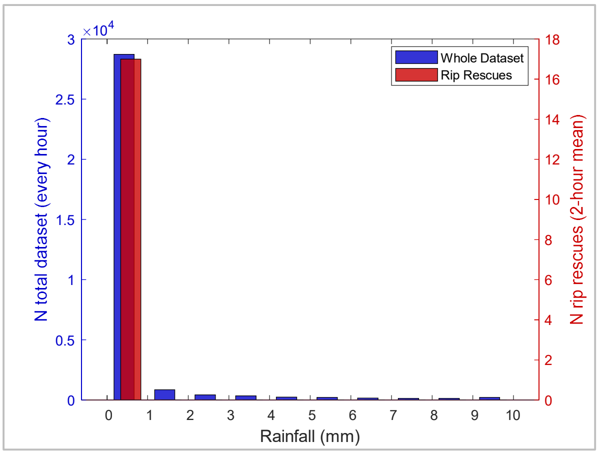


Total dataset vs rip current related wave height and wind speed



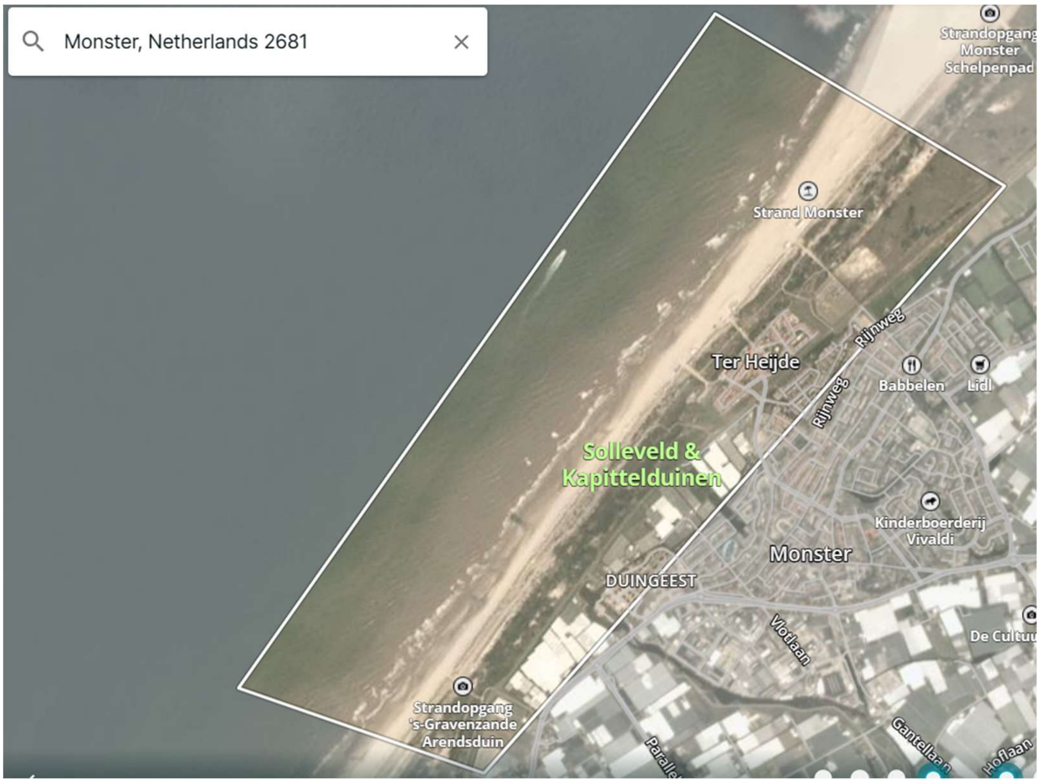


Total dataset vs rip current related temperature and sunshine

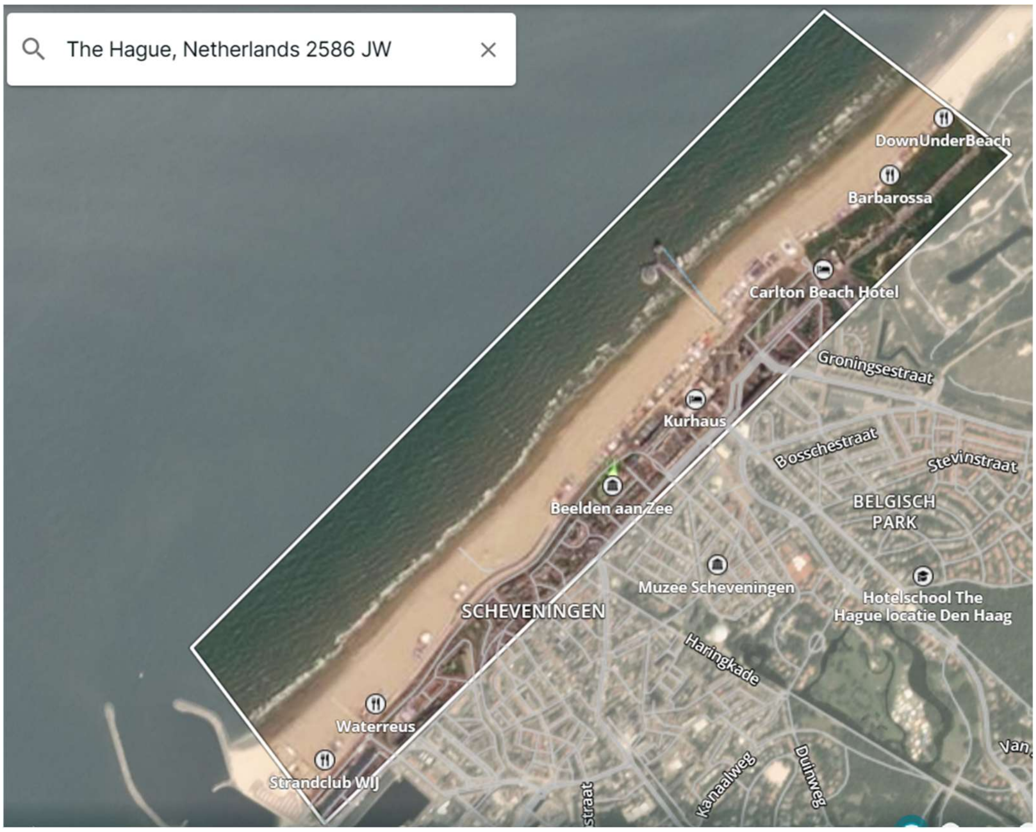


Total dataset vs rip current related rainfall

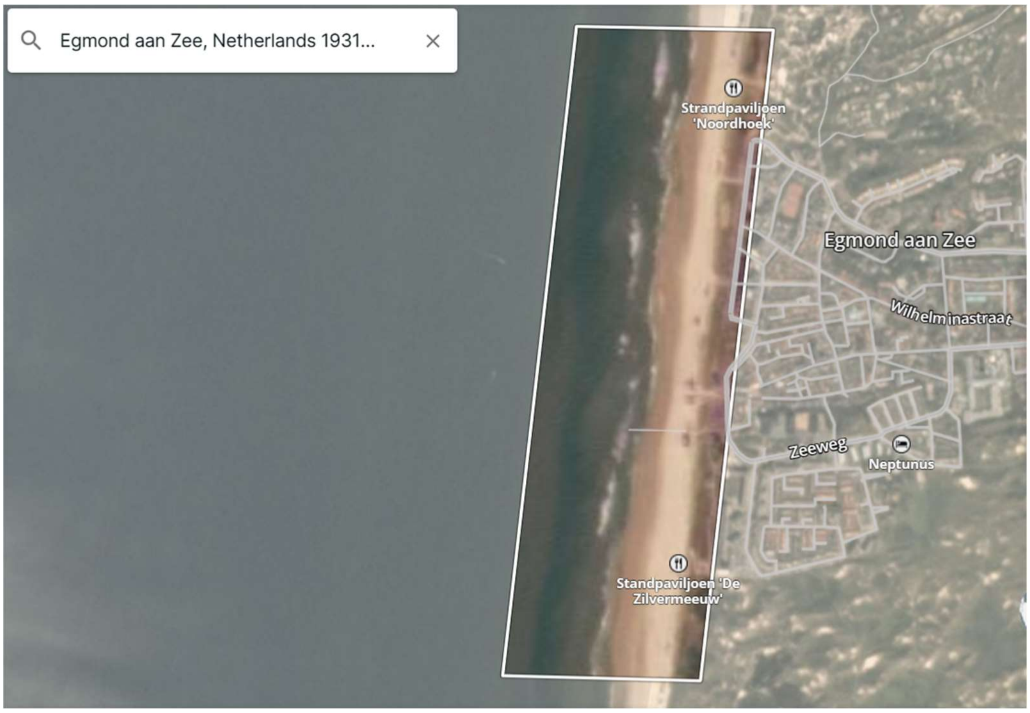
Appendix I – Local high rescue situations



Satellite image Monster from 10-08-2020



Satellite image The Hague from 17-07-2021

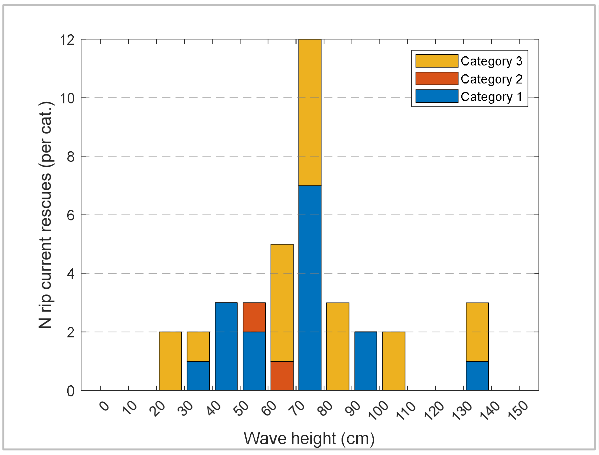


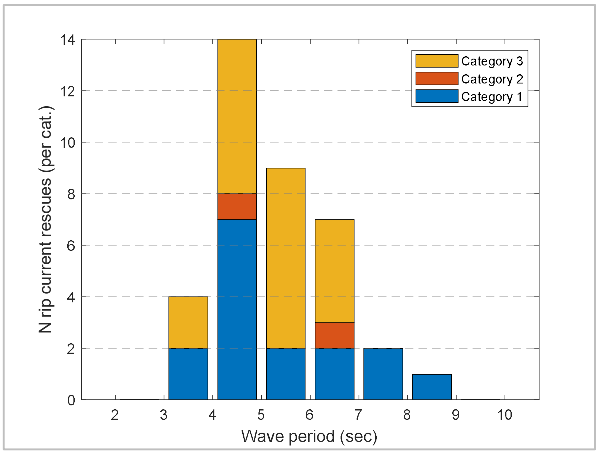
Satellite image Egmond from 20-07-2023

Satellite image The Hague from 07-08-23

Appendix J – Wave height and-period over different rip certainties

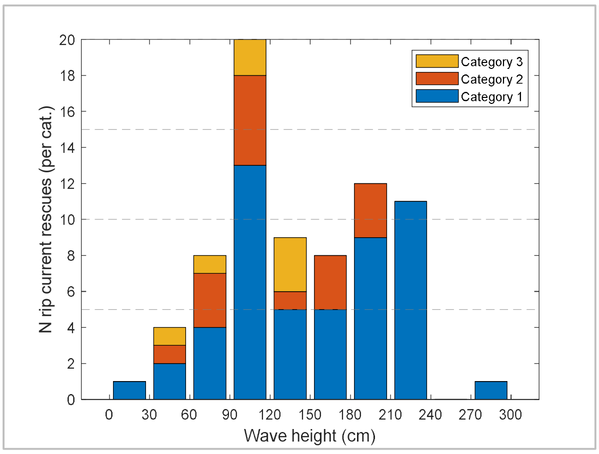
1. Egmond

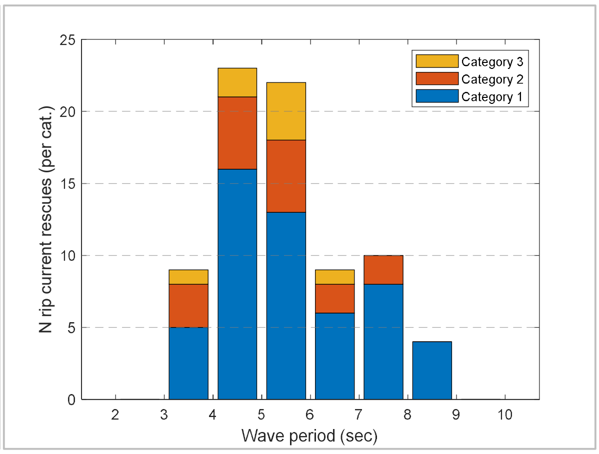




Comparison between categories: Wave height and Wave period

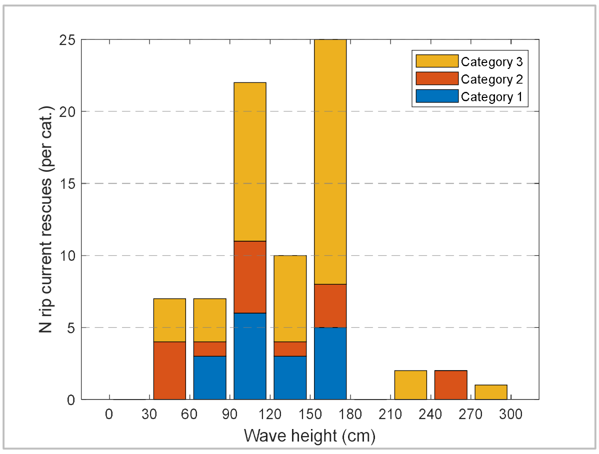
2. The Hague

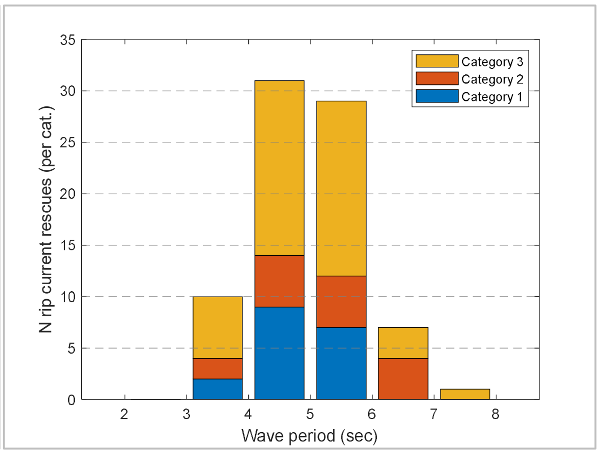




Comparison between categories: Wave height and Wave period

3. Monster





Comparison between categories: Wave height and Wave period

Appendix K – Lifeguard incident report

Date: 19/08/2015 | Form #: 26 | Location: Lacanau

Lifeguard's station: Northern beach — Start: 17 h 15 — End: 18 h 00

Accident on the beach ☑ Yes ☐ No
Pattroled area ☑ Yes ☐ No
Bathing zone ☑ Yes ☐ No

Flag: ☐ G ☑ Y ☐ R — Patrolled hour ☑ Yes ☐ No

IDENTITY

NAME: XXXXXX xxxx — Age: 29 — M ☐ F ☑

Adress: 23, Second Street, 33600

ACCIDENT

Activity: ☑ Wading / swimming ☐ Surfing ☐ Bodyboarding ☑ Shorebreak ☐ Other

► Accident description: In the bathing zone she got pounded by a shorebreak, swallowed a little bit of water. She was able to go back to shore alone.

Saved by: ☐ Lifeguard ☐ Helicopter ☐ Boat ☐ Bystander ☑ Alone ☐ Other

MEDICAL REVIEW

Faint:: ☐ Yes ☑ No

Desease: ☐ Yes ☑ No

● *Drowning stage* ☐ 1 ☑ 2 ☐ 3 ☐ 4

Traumatology:

	Head	Spine	Limb	Thorax	Abdomen
Contusion					
Wound		X			
Fracture					X
Luxation	X			X	X

● *Other*

► Summary: The victim is shocked, with moderate respiratory impairment

VITAL SIGNS

Conscious ☑ Yes ☐ No ☐ Initial loss of consciousness
Breathing ☑ Yes ☐ No ☐ Labored
Pulse: ☑ Yes ☐ No

SEVERITY

☐ No severity ☐ Mild severity
☑ Severe ☐ Very severe
☐ Fatal

CARE

☐ O_2 ☐ Cervical collar ☐ Upper airway release ☐ Ventilation ☐ Recovery position ☐ Chest compression

TRANSPORT FROM THE BEACH

☑ Fire brigade ☐ Emergency Medical Services ☐ Helicopter ☐ Private Ambulance ☐ On their own ☐ Local doctor

Towards: ☐ Hospital ☑ Clinic ☐ Doctor office ☐ No transportation ☐ Medical committee

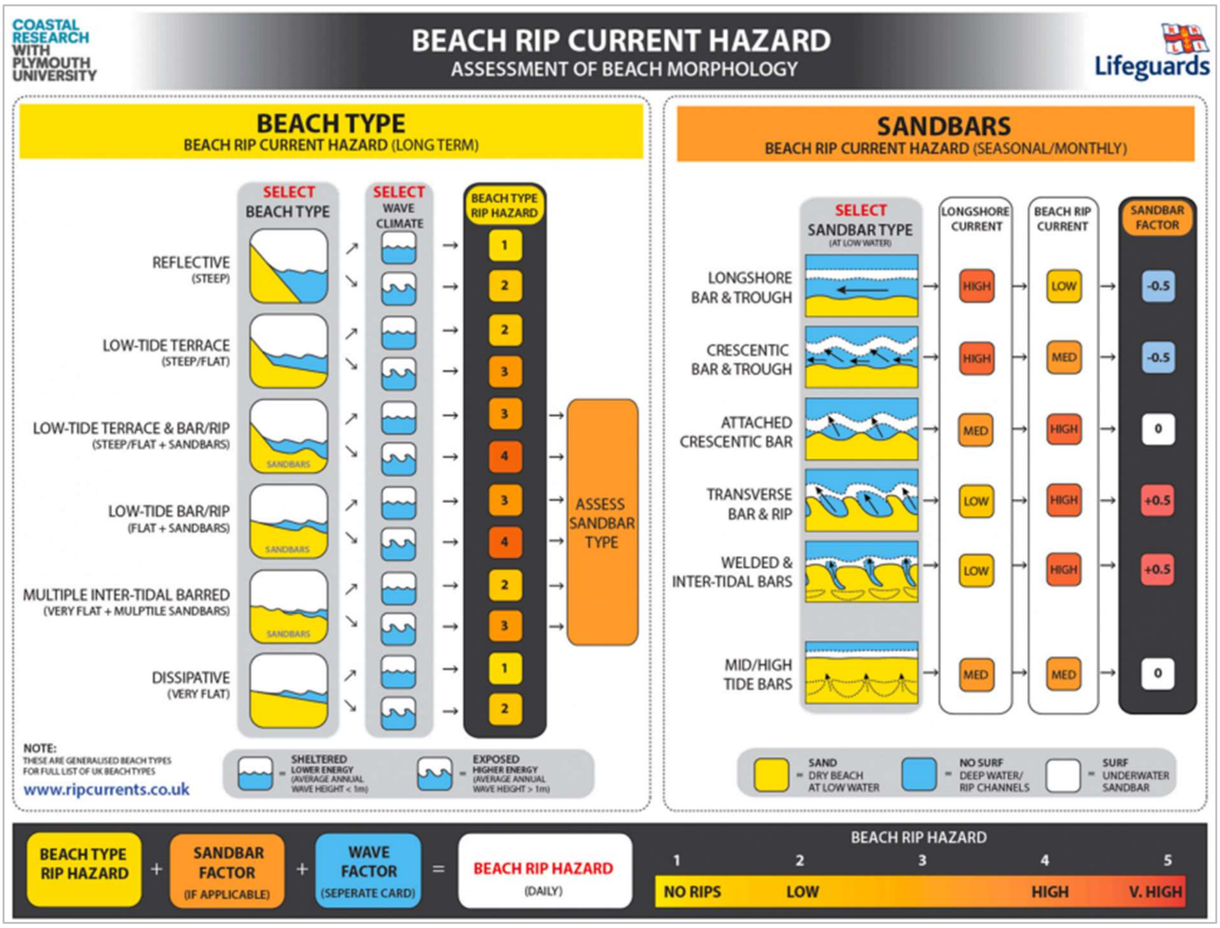
XXXXX — Location name — ☐ REFUSAL

► *Intervention lifeguard(s):* (optional) XXXXX — XXXXX

Lifeguard Chief: XXXXX

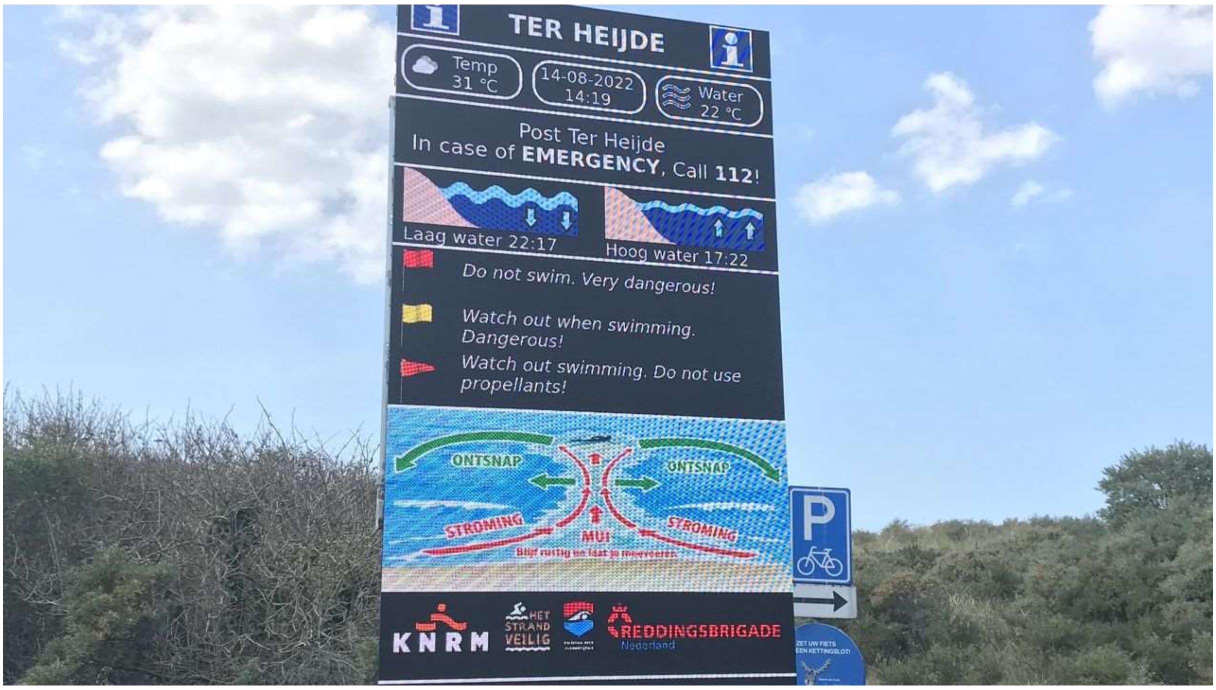
Example of a notation form, increasing the unambiguousness. By including different possibilities of bather emergency situations, it can help in specific research (Source: Castelle et al., 2018)

Appendix L – Rip current assessment.



Visualisation of rip currents on various local beach situations (Source: Scott et al., 2022)

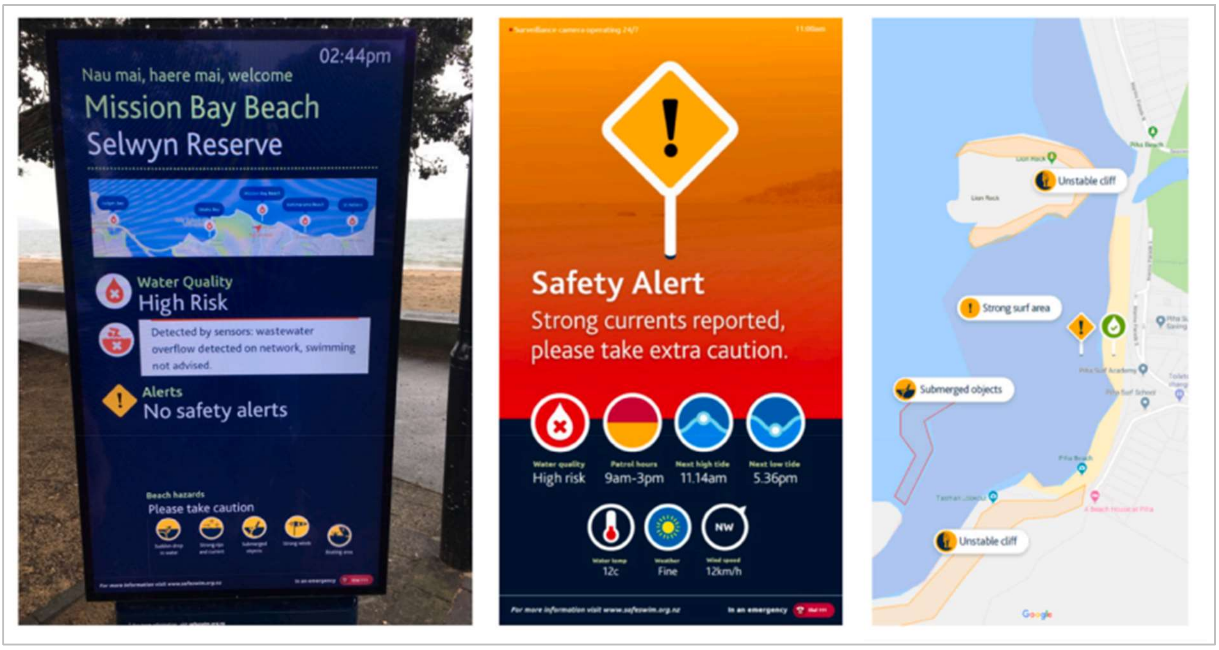
Appendix M- current rip safety measures



Example of on-site (rip current) information (source: NIVZ)

Current method of Danger flags near dangerous rip currents, not applied along the whole Dutch coast yet (source: NIVZ)

Appendix N – Safety design



Example of extra local information and a free to use safety app (Scott et al., 2022)