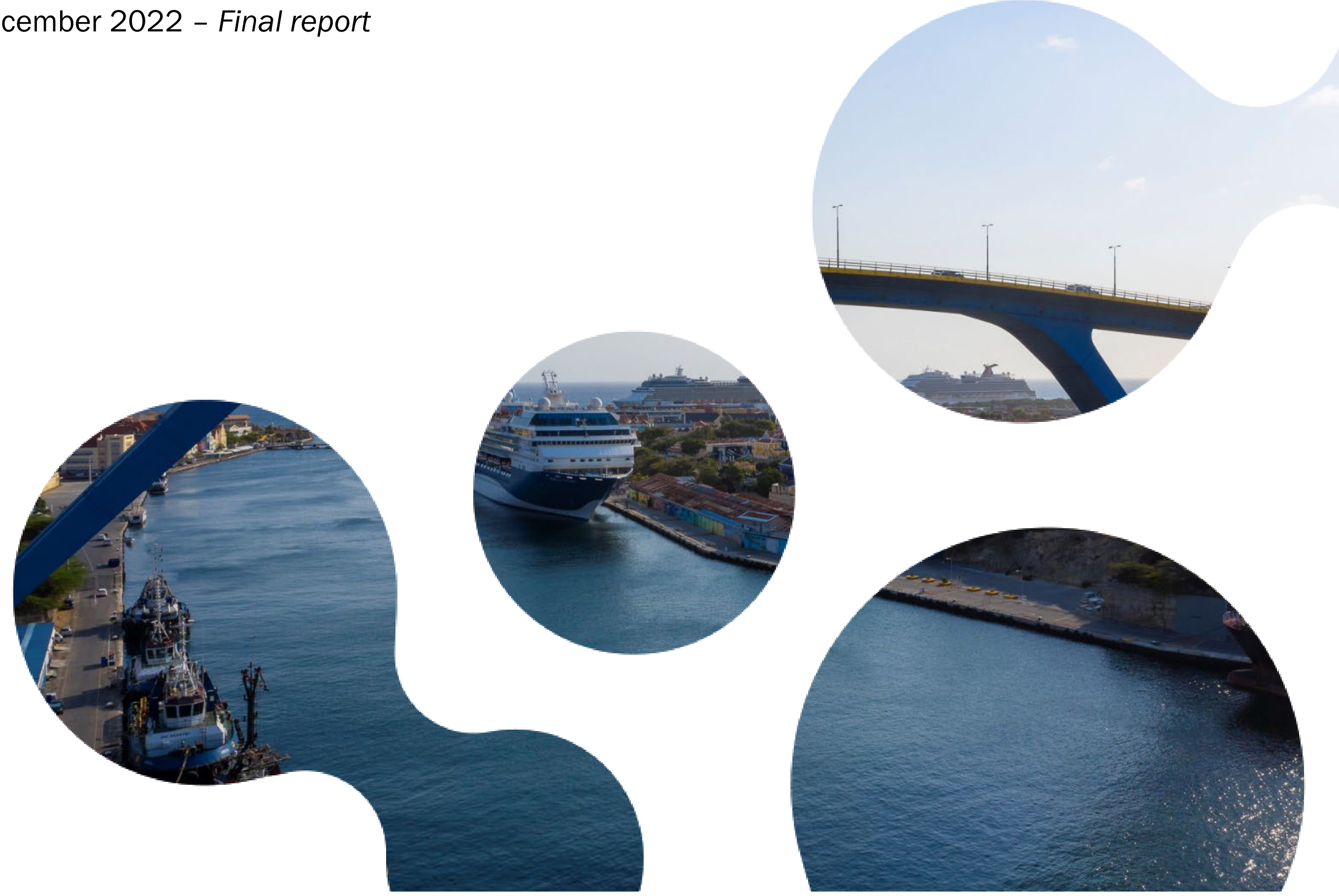
Climate Risk Assessment Curaçao Ports Authority

Roadmap report

EcoVision
Climate Adaptation Services (CAS)

December 2022 – *Final report*



Client:

Name:	Curaçao Ports Authority (CPA)
Contact person:	Albert Zwueste
Address:	Werf de Wilde z/n P.O. Box 689. Curaçao

Contractor:

Name:	EcoVision N.V.
Contact person:	Rob Kelder
Phone:	+599 9 736 9533
Address:	Mauritslaan 1, Curaçao
E-mail:	consultants@ecovisionnv.com

Authors: Timo Kelder, Felix van Veldhoven, Rob Kelder, Javier Diaz, Michel Ruijter

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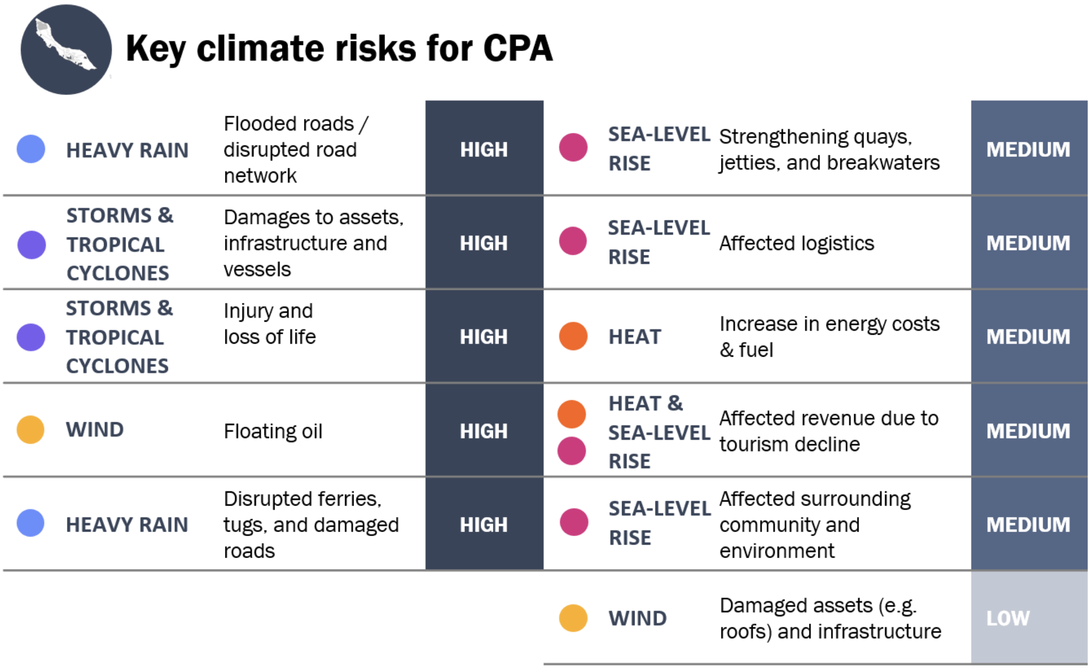
Table of contents

Summary for decision-makers

The Curaçao Ports Authority (CPA) is seeking a climate adaptation strategy to cope with the impacts of climate change, ensuring the safety and security in the ports in an environmentally responsible matter. In support of this strategy, this study provides CPA with an understanding of climate change hazards, impacts and risks, as well as offering a roadmap with possible follow-up steps and research opportunities.

Curaçao has already become warmer over the years due to climate change. Currently, the average annual maximum is around 33°C, with a record temperature of 38.3°C. By 2050, it will likely be 36°C annually with outliers of 42°C. Heavy rainfall is expected to increase in intensity and the sea level is expected to rise faster in the coming decades than in recent decades. In a world where we keep emitting fossil fuels, the sea level is expected to rise with 28 centimeters by 2050 and 86 centimeters by 2100. Without adaptation action, this could potentially lead to permanent flooding of the Waaigat area, Zeelandia, and several places around the Schottegat.

In a workshop with CPA staff and stakeholders, including government agencies and relevant ministries of Curaçao, the impacts of the changing climate to the harbor and its stakeholders were assessed. The key climate risks are linked to the most impeding impacts that are expected to occur in the future. The risks that are both likely to occur frequently and cause severe damage, deserve specific attention when working towards climate action. The figure below summarizes the key climate risks that were identified together with CPA's stakeholders.



Key climate risks for CPA

●	**HEAVY RAIN**	Flooded roads / disrupted road network	**HIGH**	●	**SEA-LEVEL RISE**	Strengthening quays, jetties, and breakwaters	**MEDIUM**
●	**STORMS & TROPICAL CYCLONES**	Damages to assets, infrastructure and vessels	**HIGH**	●	**SEA-LEVEL RISE**	Affected logistics	**MEDIUM**
●	**STORMS & TROPICAL CYCLONES**	Injury and loss of life	**HIGH**	●	**HEAT**	Increase in energy costs & fuel	**MEDIUM**
●	**WIND**	Floating oil	**HIGH**	● ●	**HEAT & SEA-LEVEL RISE**	Affected revenue due to tourism decline	**MEDIUM**
●	**HEAVY RAIN**	Disrupted ferries, tugs, and damaged roads	**HIGH**	●	**SEA-LEVEL RISE**	Affected surrounding community and environment	**MEDIUM**
				●	**WIND**	Damaged assets (e.g. roofs) and infrastructure	**LOW**

Figure 1: key climate risks for ports of Curaçao.

1. Introduction

The Curaçao Ports Authority (CPA) manages the ports and harbors of Curaçao. CPA is now seeking a climate adaptation strategy to cope with climate change impacts and ensure the safety and security in the ports in an environmentally responsible matter. Investing in climate resilience upfront by taking preventive action against a range of climate hazards is forward-looking and cost effective. This report sets out a scoping plan to develop the CPA climate adaptation strategy.

1.1. Objectives

The goal of this project is to provide CPA with an understanding of the **hazards**, **impacts** and **risks** of climate change and to offer a **roadmap** with possible follow-up steps.

The following ports/harbors are included in the study: Willemstad (main port of Curaçao with various port facilities, jetties, and quays), Bullenbaai (Oil terminal, 5 jetties), Caracasbaai (2 jetties for berth longer periods), Fuikbaai (bulk quay). Figure 2 shows the locations of the various ports/harbors.

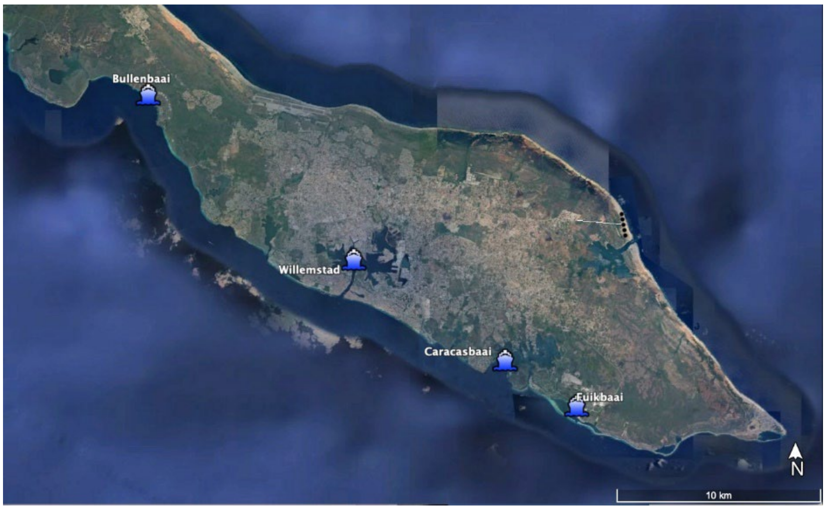


Figure 2: Location of harbors incorporated in climate change study.

1.2. Structure of the report

Climate risk is caused by harmful climate events and trends (hazards), which potentially have negative impacts on CPA's assets, operations, and infrastructure. This climate risk assessment is therefore structured based on three steps: (1) the climate hazards assessment, where we identify the relevant hazards for CPA, including their historical trends and projections; (2) the climate impact assessment, where we identify and prioritize sector-based impacts; and (3) the climate risk assessment, where we determine CPA's key climate risks together with its stakeholders (Figure 3).

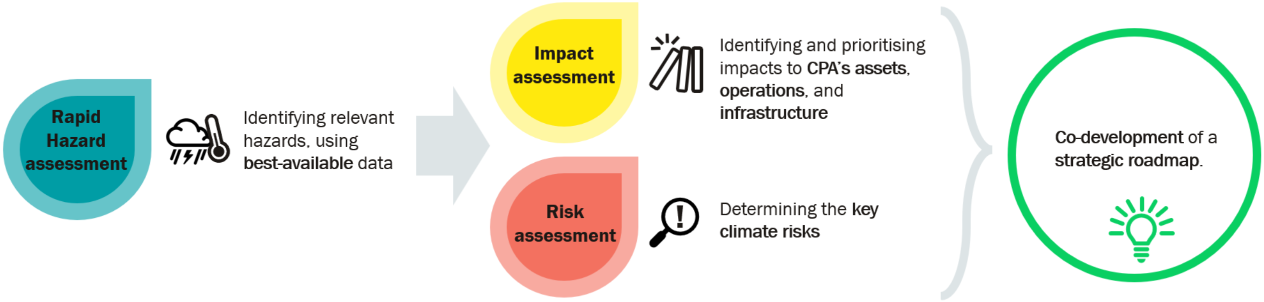


Figure 3: Structure of the climate risk assessment and resulting roadmap report.

In the next chapter of this report, more detail is provided on the definitions of climate hazards, impacts, and risk, what climate scenarios are, and what types of climate models exist. Chapters 3-5 follow the three steps of the climate risk analysis: from the changing climate (Chapter 3), through impacts for CPA and its stakeholders (Chapter 4), to the key climate risks (Chapter 5). The report is concluded with follow-up steps related to research opportunities, adaptation goals and targets, and identifying adaptation actions (Chapter 6).

2. Understanding physical climate risk

2.1. How we define risk

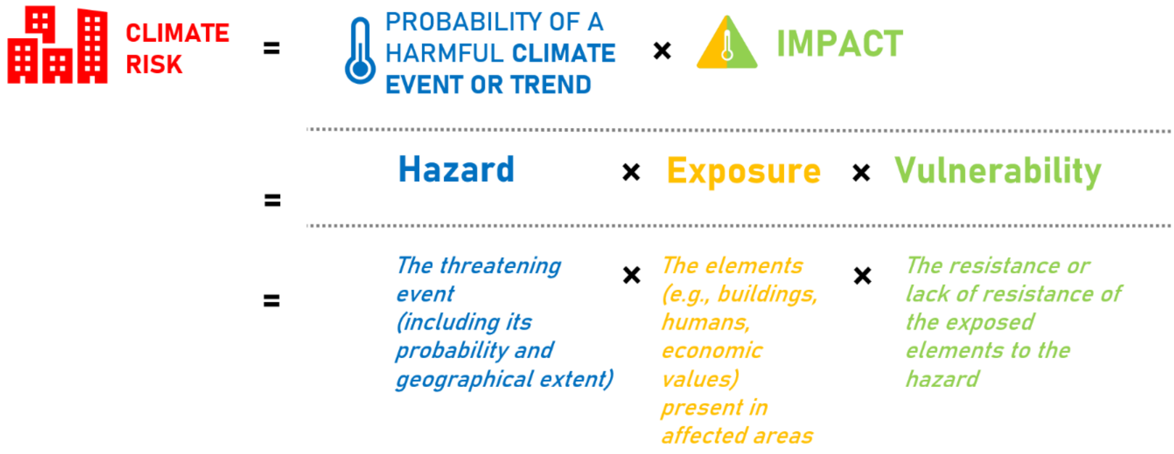


Figure 4: Framework for climate risk assessments.

The Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6, 2022) offers a conceptual framework for the assessment of risks associated with climate change. Climate risk is caused by harmful climate events that have negative impacts on places worldwide. Consequences are a result of the interplay between the hazards and what is being referred to as components of exposure and vulnerability (Figure 4). We follow the definitions of the United Nations office for Disaster Risk Reduction (UNDRR) in this project. The definitions of hazard, exposure, and vulnerability below are from the UNDRR glossary (*www.undrr.org/terminology*) and a short addition or explanation on each definition is added as well.

- **Hazard**: "A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation." (UNDRR glossary, consulted September 2020). Hence, it is a threatening event, including its probability and geographical extent. Note the word "may", which implies that an event does not always cause (negative) impacts as this depends on the exposure and vulnerability components.
- **Exposure**: "The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas." (UNDRR glossary, consulted September 2020). Hence, these are all the elements present in affected areas, such as citizens, flora & fauna, buildings, and (critical) infrastructure.
- **Vulnerability**: "The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards." (UNDRR

glossary, consulted September 2020). Hence, this is the (lack of) resistance of the exposed elements to the hazard.

- **Climate risk**: "The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of (1) a climate-related hazard, (2) exposure, (3) vulnerability" (adapted from UNDRR glossary, consulted September 2020). Hence, facing a climate hazard, people, assets, etc. may be exposed and vulnerable in different ways, depending among others on their location and capacity to cope and adapt. The interplay of a hazard, the exposed elements and their vulnerability determines climate risk.

2.2. Scenarios

Climate scenarios represent the boundaries within which climate change may occur. Climate scenarios are not predictions. Different scenarios are calculated because human choices determine future emissions and thus future climate. Because the exact future emissions of greenhouse gases are unpredictable, the IPCC has developed a range of possible scenarios for the concentration of greenhouse gases. These scenarios outline a range of possible futures, based on a range of emission levels and other aspects such as land use changes. Scenarios are therefore possible stories about how populations will grow, how land will be used, how economies will evolve, and the atmospheric conditions (and therefore, climate forcing) that would result for each storyline.

Once every seven years or so, the IPCC publishes a report that summarizes all known knowledge about current climate and climate change, known as 'Assessment Reports'. The IPCC's fifth assessment report (AR5) was written in 2013 based on CMIP5 climate models. The IPCC's sixth and most recent Assessment Report (AR6), of which the first part was published in 2021, is based on CMIP6 models. CMIP6 uses a new generation of climate models to estimate how the climate will respond to different socioeconomic scenarios and the evolution of greenhouse gases in the atmosphere. These have a higher spatial resolution than ever before and more realistically represent the complex processes involved in the climate. This makes CMIP6 the most up-to-date, scientifically advanced database for climate science and services. Figure 5 provides an overview of the CMIP6 scenarios. The five scenarios may be understood as follows:

- **SSP1-1.9**: This is the IPCC's most optimistic scenario. It describes a world where global carbon emissions are cut to net zero around 2050. It is the only scenario that meets the Paris Agreement's goal of limiting global warming to around 1.5°C above preindustrial temperatures.
- **SSP1-2.6**: In this scenario global carbon emissions are cut severely, reaching net-zero after 2050. Temperatures stabilize around 1.8°C by the end of the century.

- **SSP2-4.5**: The “middle of the road” scenario, where carbon emissions start to fall mid-century, without reaching net-zero by 2100. Temperatures rise by 2.7 °C by the end of the century.
- **SSP3-7.0**: This scenario shows steadily rising emissions and temperatures, where carbon emissions roughly double by 2100. Temperatures rise by 3.6 °C by the end of the century.
- **SSP5-8.5**: The worst-case scenario. Carbon emissions roughly double by 2050. Temperatures rise by 4.4 °C by the end of the century.

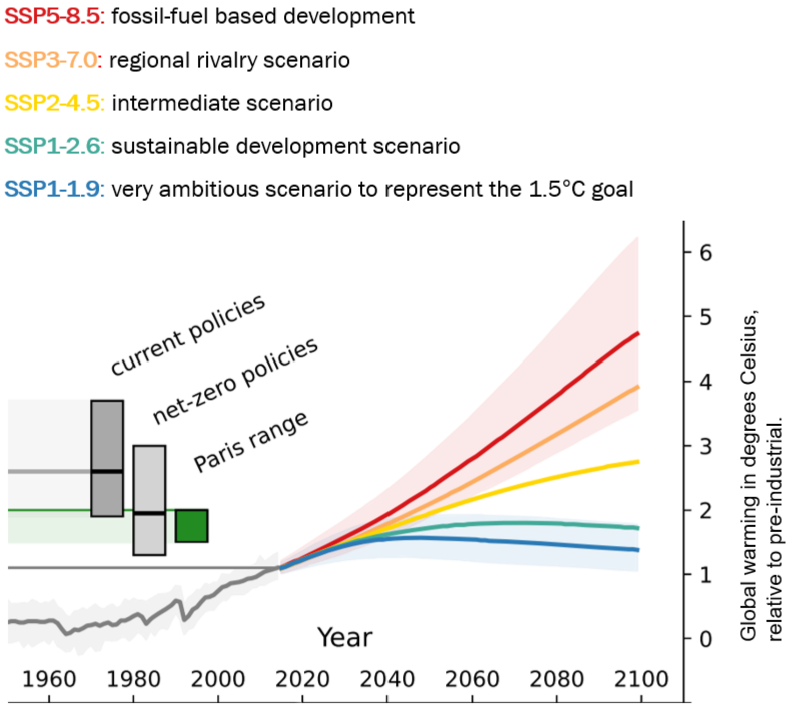


Figure 5: CMIP6 projections of future climate change from IPCC AR6. Adapted from McKay, 2022.

2.3. Types of climate models

Models are used to make predictions about the future climate. A climate model is a simulation of all the factors that can affect Earth’s climate. Climate is modelled at different spatial scales. General Circulation Models (GCMs) are used to simulate global climate and operate at spatial resolutions ranging from ~100 km2 to ~250 km2. Regional Climate Models (RCMs) can be used to simulate regional climate at a typical resolution of ~10-50 km. Climate change information is usually required at a higher spatial resolution since applications like hydrological models, forced by the data from GCMs or RCMs, operate at higher resolutions, down to several meters. At the time of writing, the latest global models (GCMs, CMIP6) have not yet been downscaled. The regional models (RCMs) used in this report therefore originate from the previous generation of global models (GCMs, CMIP5).

3. Changing climate

3.1. Methodology

This chapter covers the climate hazard assessment we carried out for CPA. We have classified the hazards into two main themes relevant to the harbor: land-based hazards, such as heat, heavy rain, or wind, and marine-based hazards, such as sea-level rise or storms and tropical cyclones. We note that tropical cycles are related to wind and heavy rainfall but we keep these themes following previous work from the Meteorological Department Curaçao (MDC) and it helps for the impact exercise. Drought is outside of the scope of CPA and is therefore not considered here. We have performed a literature review to assess the latest information of the hazard under these themes. This literature review was accompanied with quantitative data where available. For the quantitative data, we use a high emissions scenario (see section 2.2) as input for the infographics and further elaborate on the underlying uncertainties in the respective sections. The best available data and knowledge was identified during expert sessions (see Annex C) with the Meteorological Department of Curaçao and the Royal Netherlands Meteorological Institute (KNMI). The following section describes the background information, followed by sections on historical trends as well as future projections for each of the hazard themes.

3.2. Background information

Weather on earth is a chaotic system. This means that weather can change from year to year, and day to day. We experience this, for example, by one hot year followed by a colder next year. This is the ‘natural variability’ of the earth system. Climate change influences the weather – for example, it is becoming warmer -- and shifts the chance for extremes to occur. But before diving into the effect of climate change on the hazards themes it is important to mention that much of the year-to-year variability in weather of Curacao is affected by the SST of the equatorial Pacific through different tropical atmospehric patterns. This is the well-known El Nino-Southern Oscillation (ENSO). In short, warm sea temperatures (El Niño) lead to dryer conditions and less tropical cyclones whereas cool temperatures (La Niña) result in more rainfall and a higher chance of tropical cyclones to form. Figures 6-8 provide a schematic overview of neutral, El Niño and La Niña conditions.

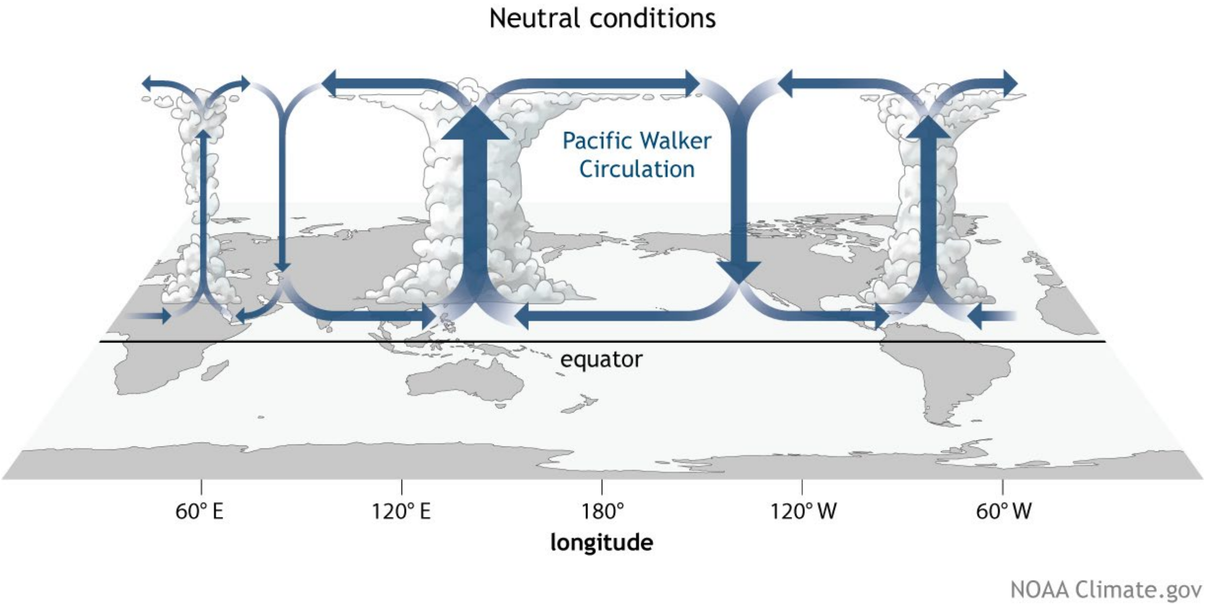


Figure 6: Schematic overview of neutral conditions. Source: NOAA.

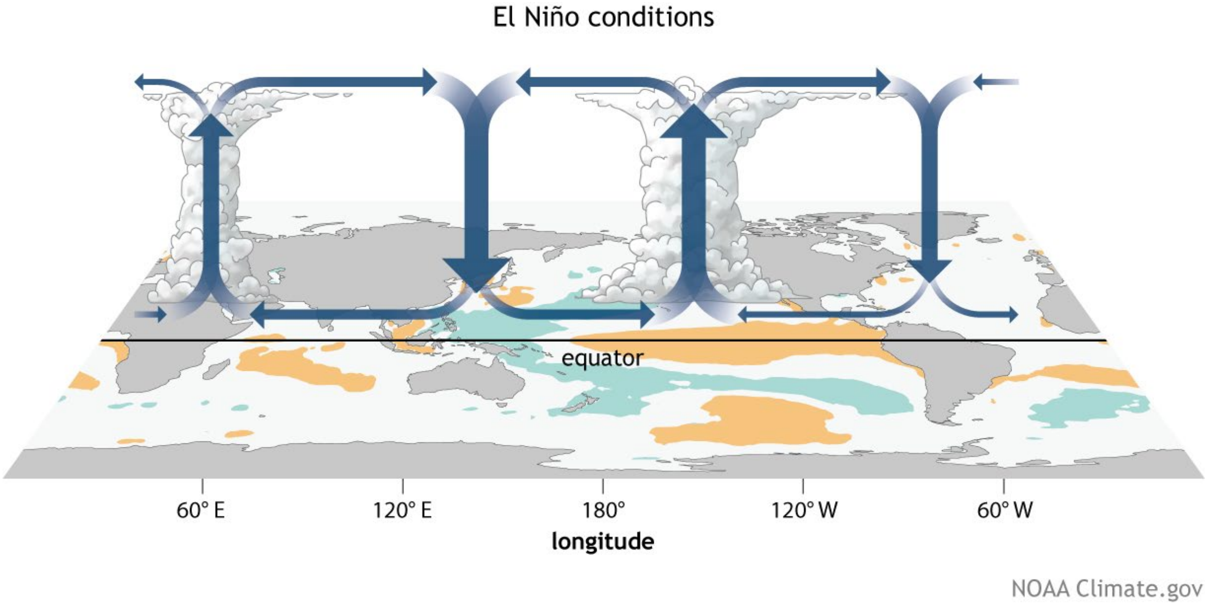


Figure 7: Schematic overview of El Niño conditions. El Niño relates to warm sea temperatures northwest of South America, leading dryer conditions and fewer tropical cyclones. Adapted from NOAA.

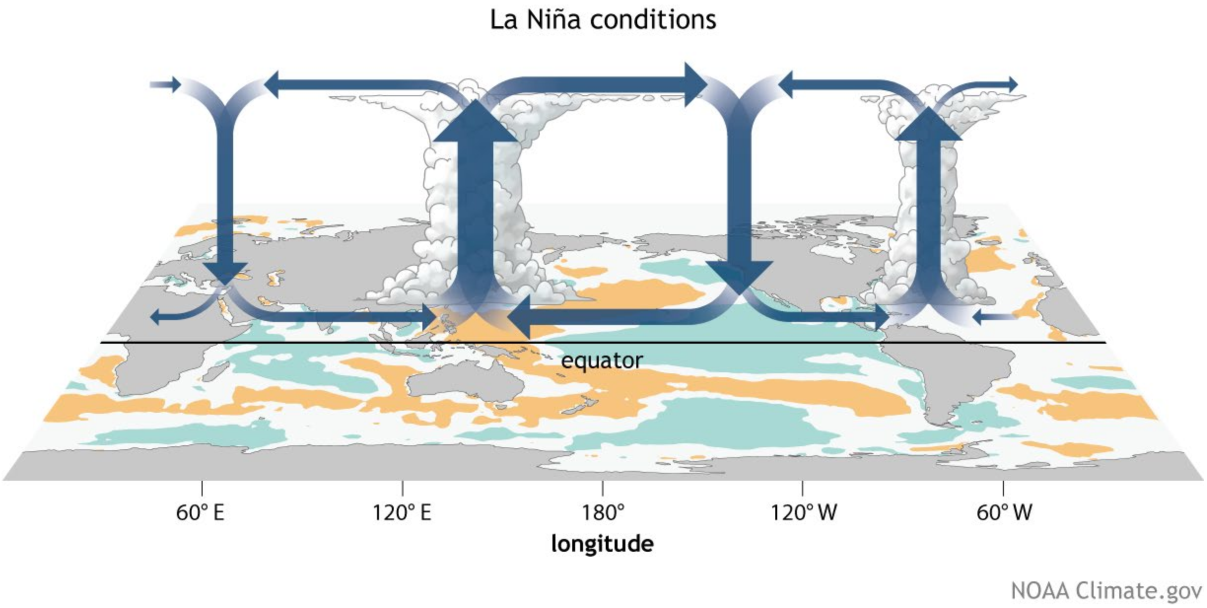


Figure 8: Schematic overview of La Niña conditions. La Niña relates to cold sea temperatures northwest of South America, leading wetter conditions and more tropical cyclones. Source: NOAA.

3.3. Land-based hazards

The land-based hazard theme consists of heat, heavy rainfall, and wind gusts.

Heat

The heat hazard theme consists of the ‘slow onset event’ of rising average temperatures, as well as the extreme events of maximum temperature and thermal comfort.

Average temperature

2050

Seasonal change in temperature

Dec - Feb	27 + 1.9°C
Mar - May	28 + 2°C
Jun - Aug	29 + 2°C
Sep - Nov	29 + 2.1°C

The average temperature is fairly stable throughout the seasons. December-February are the coldest months and September is the warmest month of the year (Meteo Dienst Curaçao). Measurements at Kas Chikitu and Hato show that the average temperature has risen over the last century (Figure 9).

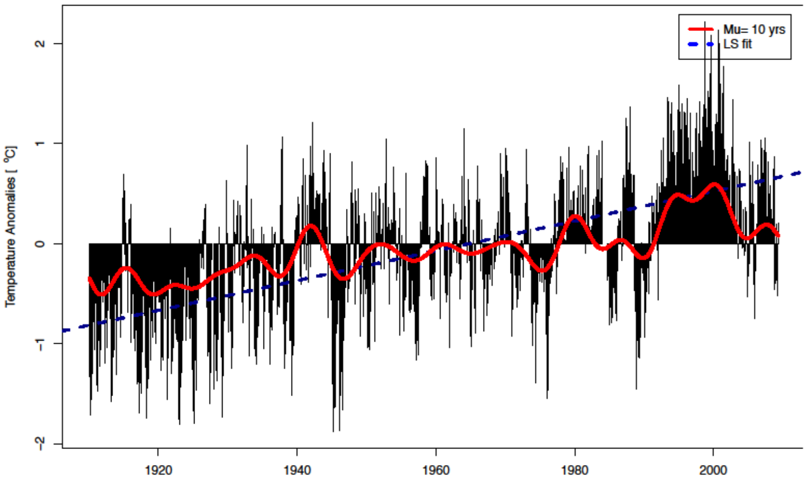


Figure 9: Temperature anomalies for measurements at Kas Chikitu and Hato stations combined. Source: Meteo Dienst Curaçao.

Projections show that average temperatures increase with **about 2 C° by 2050** under RCP8.5. There is little variability in the trend throughout the season, with September and October being the months with the largest changes in average temperature[1].

Extreme temperature

Maximum temperature	NOW	2050
Yearly	32.8°C	36°C
Record	38.3°C	42°C

There is an extremely likely increase in warmer and more frequent hot days and nights, warm spells and heat waves (P.J. Girigori, 2011). The average maximum temperature for September (the warmest month of the year) is **32.8 C°**. The record is **38.3 C°** for the period 1981-2010 (Meteo Dienst Curaçao).

Figure 10 shows the observed maximum and minimum temperatures for Hato, Curaçao (P.J. Girigori, 2011). The minimum of daily minimum temperatures is a good indicator for 'sticky' nights: it shows how warm it was at the coldest moment during the night. The maximum of daily maximum temperatures is a good indicator for how hot it can become during the day. Both these indicators are increasing over time, with about a **2 C° increase over the last century** (P.J. Girigori, 2011).

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[1] Source: CMIP5 regional projections, CORDEX Central America (Bias-adjusted). Time period: 2041–2070, Historical period: 1981–2010. Indicator: Temperature, temperature (annual mean). Model results for an area covering the Lat./Lon. : 12.17, -68.98.

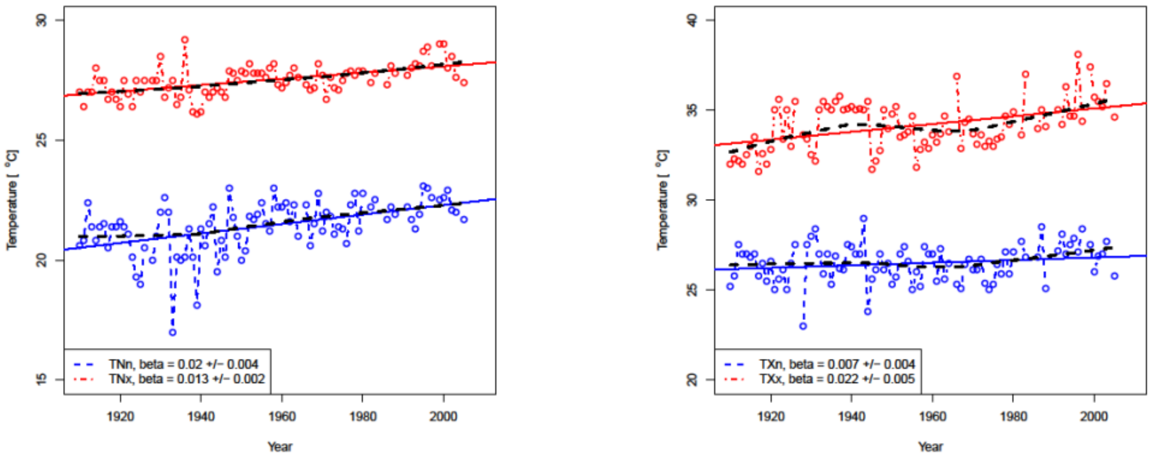
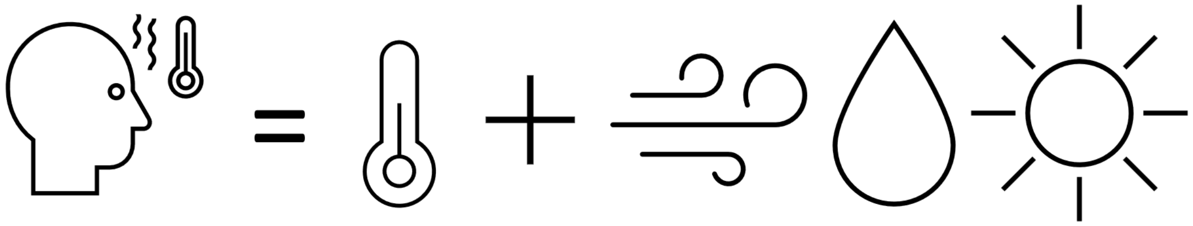


Figure 10: Maximum (TNx) and minimum (TNn) of daily minimum (left) and daily maximum (right) temperatures. Source: Girigori, P.J. (2011).

Future projections of annual mean maximum temperatures show about **3.2 °C increase for 2050** under RCP8.5[2]. September and October show the largest trends in maximum temperatures (3.4 C°). To obtain annual and record maximum temperatures for 2050, we add the projected increase for September to the historical values (see two paragraphs above), resulting in **36.2 C° and 41,7 C°** [2].

It should be noted that the observations are for the station Hato. The values could be different for the harbor. Especially in urban environments, or locations with much asphalt, temperatures may rise much above the values measured at the station in Hato. These values also do not include wind or relative humidity, which can be important factors for the thermal comfort. Thus, local factors may make the conditions even more unbearable for outside workers.

A first exploratory assessment shows a decline in the heat index due to a decline in relative humidity (see Annex – Extended hazard assessment). This assessment does not yet include wind or sunshine and requires further study and validation.



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[2] Source: CMIP5 regional projections, CORDEX Central America (Bias-adjusted). Time period: 2041–2070, Historical period: 1981–2010. Indicator: Temperature, max temperature. Model results for an area covering the Lat./Lon. : 12.17, -68.98.

Heavy rainfall

Record Trend

Maximum rainfall in 24h

117.8 mm

+ increase in intensity

The heavy rain hazard theme consists of extreme rainfall resulting in flash floods and landslides.

There is a very likely (>90%) increase in rainfall intensity and a more likely than not (>50%) increase of extreme rainfall events over the historical period (P.J. Girigori, 2011). The trend is assessed for the R99p index, which is an indicator for extreme rainfall. R99p shows the annual sum of daily precipitation larger than the 99th percentile, and has increased over last century (Figure 11). Heavy rainfall often occurs locally. This also means that there is high spatial variability in rainfall: it might rain on Hato, but not in the Harbor. The west of Curaçao (Band'abou) is generally wetter (~15%) than the east (Band'ariba) (de Palm, 1985).

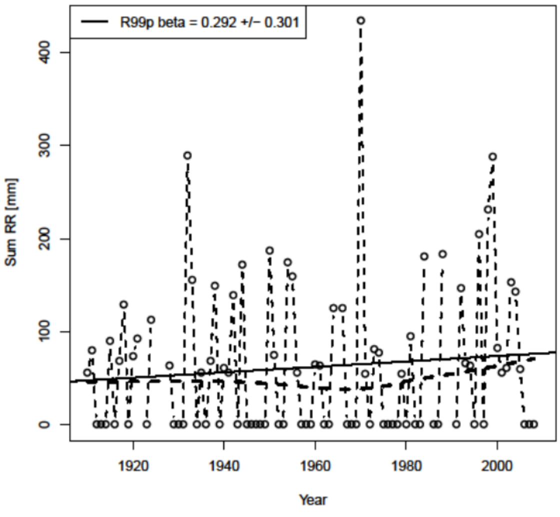


Figure 11: Trends in extreme rainfall. Source: P.J. Girigori, (2011).

For the future, we expect more extreme precipitation from more intense tropical cyclones. Figure 12 shows an image of the flooding during storm Tomás in 2010. Furthermore, for the future trend we mostly rely on the historical information because it is hard to trust climate models for the small scale processes, such as convection, that are relevant for Curaçao (see more detail in Annex A – Extended hazard assessment).

Figure 12: An image of floods caused by Tomás in November 2010.

Figure 13 shows the 'discharge', or flow of water, for a heavy rainfall event of 100 mm per hour (Meteo Dienst Curaçao). This map is made using the Delft-FEWS system. Similar maps for other event magnitudes are available upon request from the Meteo Dienst Curaçao.

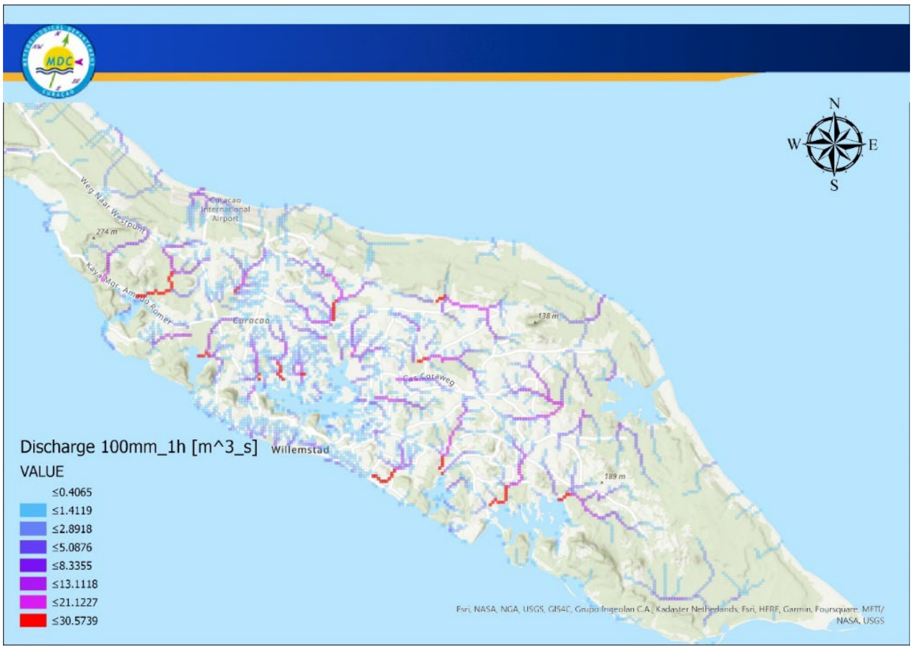


Figure 13: Discharge for a heavy rainfall event of 100 mm per hour. Source: Meteo Dienst Curaçao.

Wind

Wind gusts (Warwaru's) are not uncommon for Curaçao. These wind gusts are harder to predict than storms and cyclones, and thus can lead to more impact because it is harder to prepare for them than for storms and tropical cyclones. On average, there are 4 wind gusts a year, which leads to damage to buildings (van Duin and Sikkens, 2017). Note that these wind gusts are very local, so for the harbor the likelihood is much less than 4 times a year.

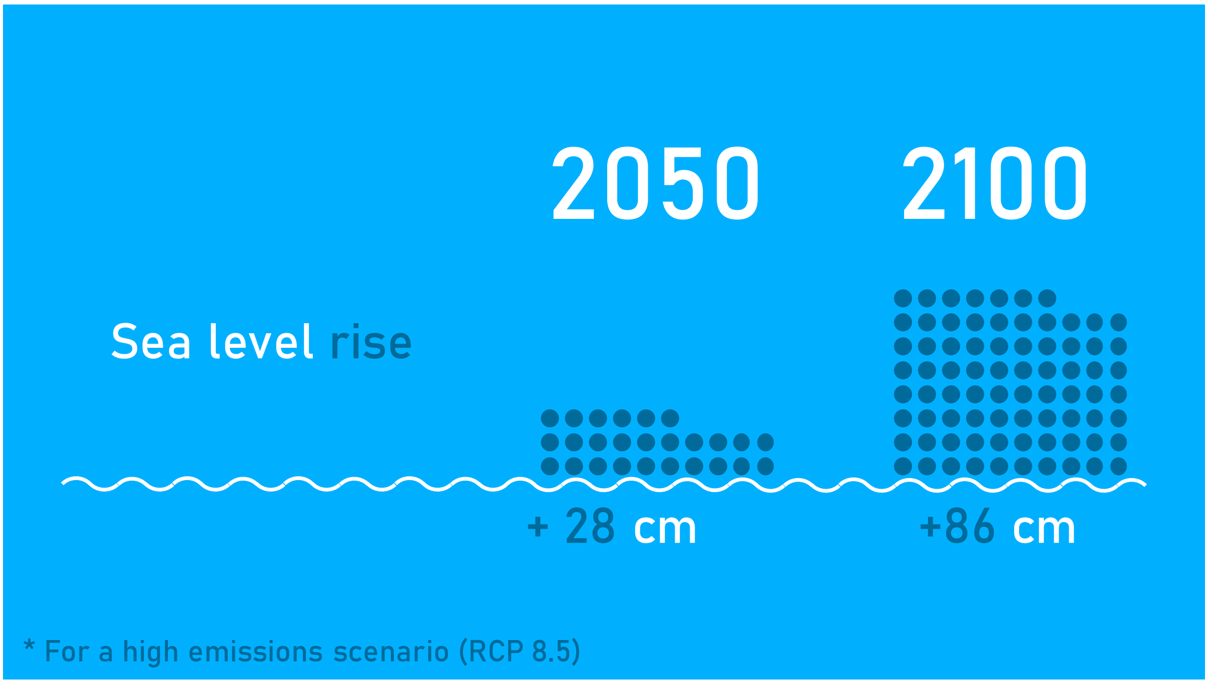
In addition to wind gusts, the wind direction is an important indicator. The wind direction for example dictates whether waves will have an impact on the coast; whether ventilation is effective; and which direction emissions from the refinery are blown.

From our session with experts, we conclude that, at this moment, it is not possible to deduce a trend in historical data or future projections. Historical data might suggest a decrease in average wind speed and a change in wind direction, but this needs to be quality checked. Also in climate models the uncertainty is large.

3.4. Marine-based hazards

This hazard theme consists of a combination of sea level rise, and storms and tropical cyclones, including waves, and storm surges. Sea level rise is a 'slow onset event', which means that this risk slowly evolves over time, whereas the other events are extreme events that have abrupt impacts.

Sea-level rise



* For a high emissions scenario (RCP 8.5)

The global sea level has been fairly constant over the last 3000 years, with an estimated sea level rise of between 0 and 0.2 millimeters per year. From the beginning of the 20th century this relatively slow rate accelerated to a larger rate of over 1 mm/yr. Satellite data is available since 1992, providing better global estimates. Since 1992 the global average sea level rise is estimated as 3.1 mm/yr., although this is not confirmed by land stations. Local sea level rise can be different to the global estimate mostly due to a change of the ocean circulation associated with salinity and temperature changes. When water becomes warmer or fresher (e.g. less saline) it expands and locally sea level rises. In the tropical Atlantic, the rise has been relatively uniform and close to the global mean. There is a difference of up to 2 mm/yr. between the north of the Caribbean Sea and the coast of Venezuela and Guyana.

The trend is **3.3 ± 0.4 mm/yr.** at Bonaire but the sea level can **vary by up to 4 cm** from one year to the next due to a variability of the Caribbean current (le Bars, 2022). For Curaçao, a similar trend is estimated (Figure 14), noting that ideally this trend should be validated with measurements. There are measurements in the Schottegat (operated by CPA) and in Bullenbaai (operated by MDC) but these are not long enough to validate trends.

Furthermore, plate tectonic movement can be an important factor: if the land would be subsiding, Curaçao would be more prone to flooding from the sea. A GPS station at Hato (operated by MDC) shows fluctuations in the vertical movement of Curaçao. There seems to be no trend, but the period is again too short to establish long term trends. For more detail about the plate tectonic movement and the tide measurements, we refer to Annex – Extended hazard assessment.

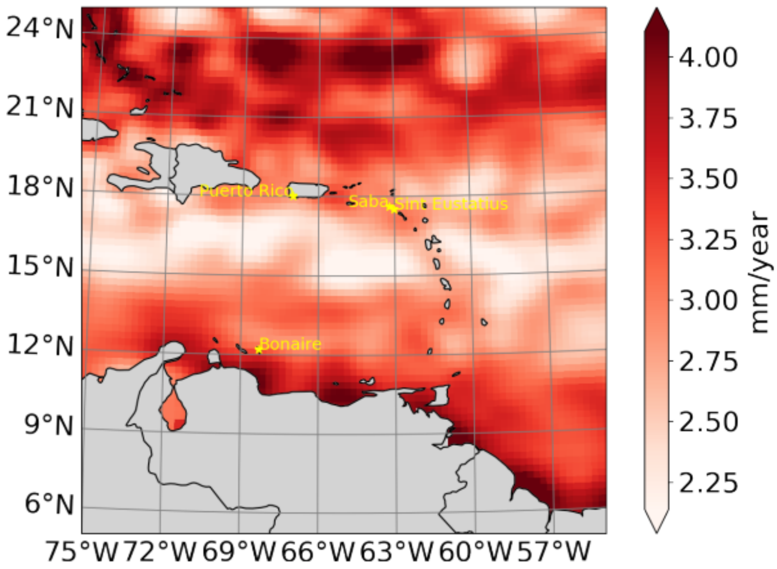


Figure 14: Trend in sea level from 1993-2019, from le Bars, 2021.

Future projections of sea level rise show an increase of 24-28 cm in 2050 to 47-86 cm in 2100 for low-high emissions (SSP1-1.9 to SSP5-8.5, IPCC AR6, Figure 15). The rate of sea level rise will be higher towards 2050 than it was in the last decades, and the sea level will rise even faster towards 2100. Therefore, it can be useful to incorporate 2100 projections as long-term planning may be useful to evaluate adaptation options with respect to a rising sea level (Haasnoot *et al.*, 2020). Note that land subsidence can be an important factor to incorporate. Subsidence is factored into these projections and only contributes 1cm for Curaçao.

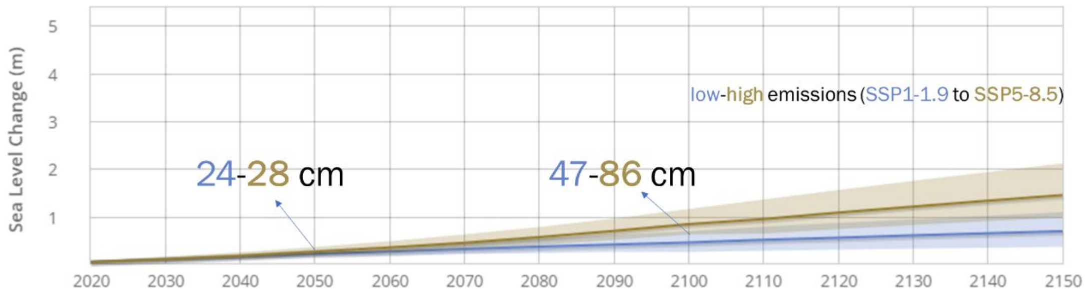


Figure 15: Sea level rise projections over time for the low and high emissions scenario. These represent the boundaries within which climate change may occur with SSP1-1.9 being a very ambitious scenario to represent the 1.5 degree goal

and SSP5-8.5 representing a scenario with fossil-fuel based development. The plot was made using the IPCC AR6 Sea-Level Projection Tool, for the point (12, -70).

Figure 16 shows the areas which likely flood due to sea-level rise by 2050 and 2100. For 2050, the 2050 low-high emissions are similar (24-28 cm). For 2100, the low-high emission scenarios show different flooded areas (47-86 cm).

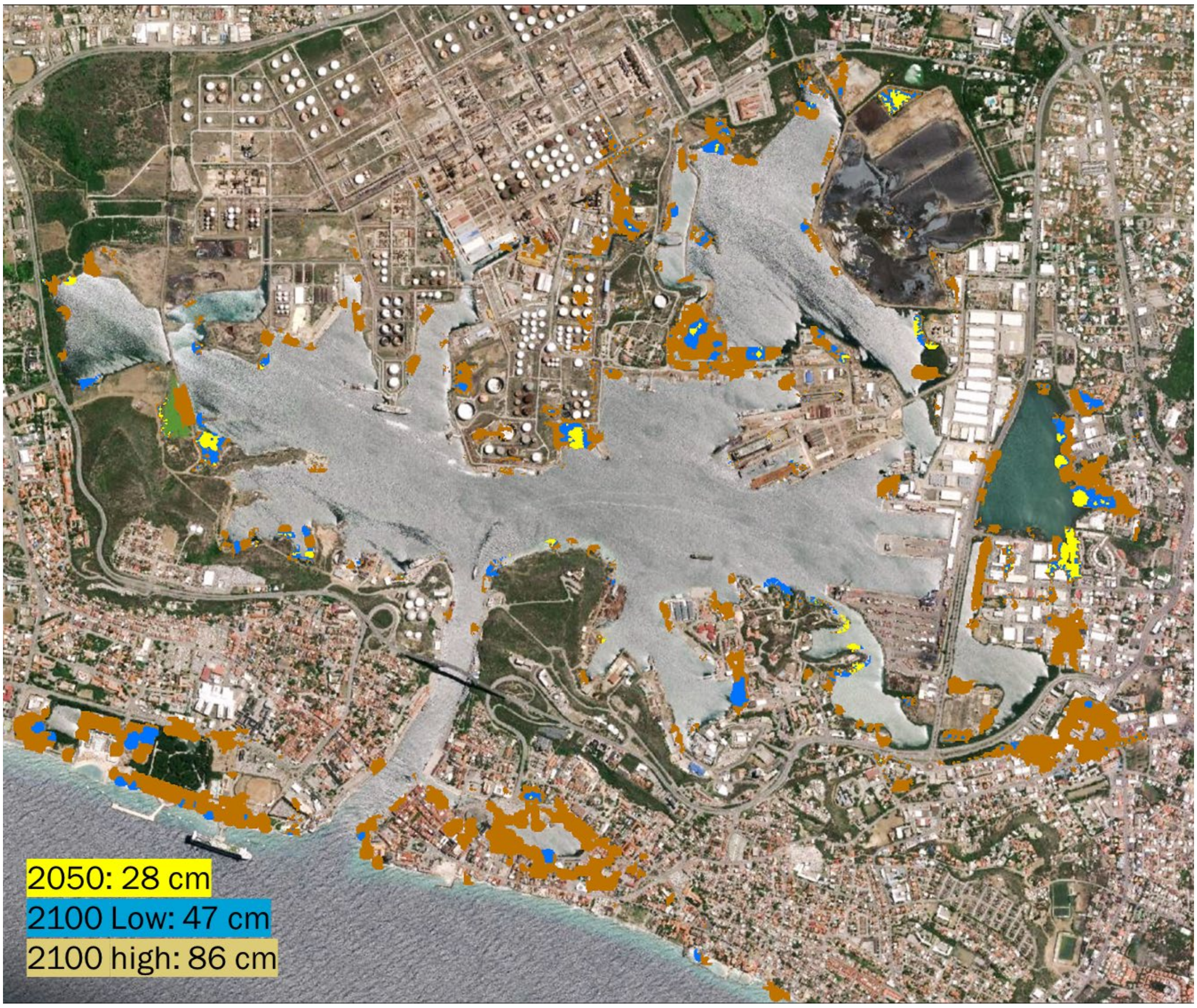


*Figure 16: Areas **likely** affected by sea-level rise. It shows the locations that might permanently be flooded in 2050 (yellow), 2100 in case of low emissions (blue) and high emissions (tan). See section 2.2 for a description of the scenarios.*

In addition to these projections, it can be useful to assess the effects over an even longer time horizon, as sea level will continue to rise beyond 2100 – even when we have stabilized our emissions (le Bars, 2022). Exploring how sea level might rise under a 'low-likelihood high-impact' scenario can be useful. Such a scenario is *unlikely* to happen, but indicates what *could* happen. The 'low-likelihood high-impact' scenario SSP5-8.5 Low Confidence shows that sea level rise of 1 meter is possible by 2100; 2 meter is plausible by 2150; and even 5 meter is within the range by 2150, but stressing that it is highly unlikely (IPCC AR6, Figure 17). Figure 18 shows the areas that *could* flood for 1; 2; and 5 meter of sea level rise. But remember Figure 16 shows the areas that are *likely* to flood by 2050 and 2100.

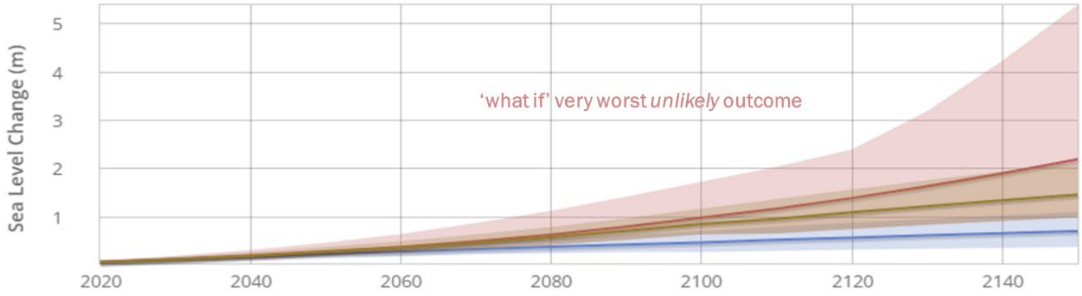


Figure 17: Sea level rise projections over time for the low-likelihood high-impact scenario: what if uncertainties turn out as bad as can be?

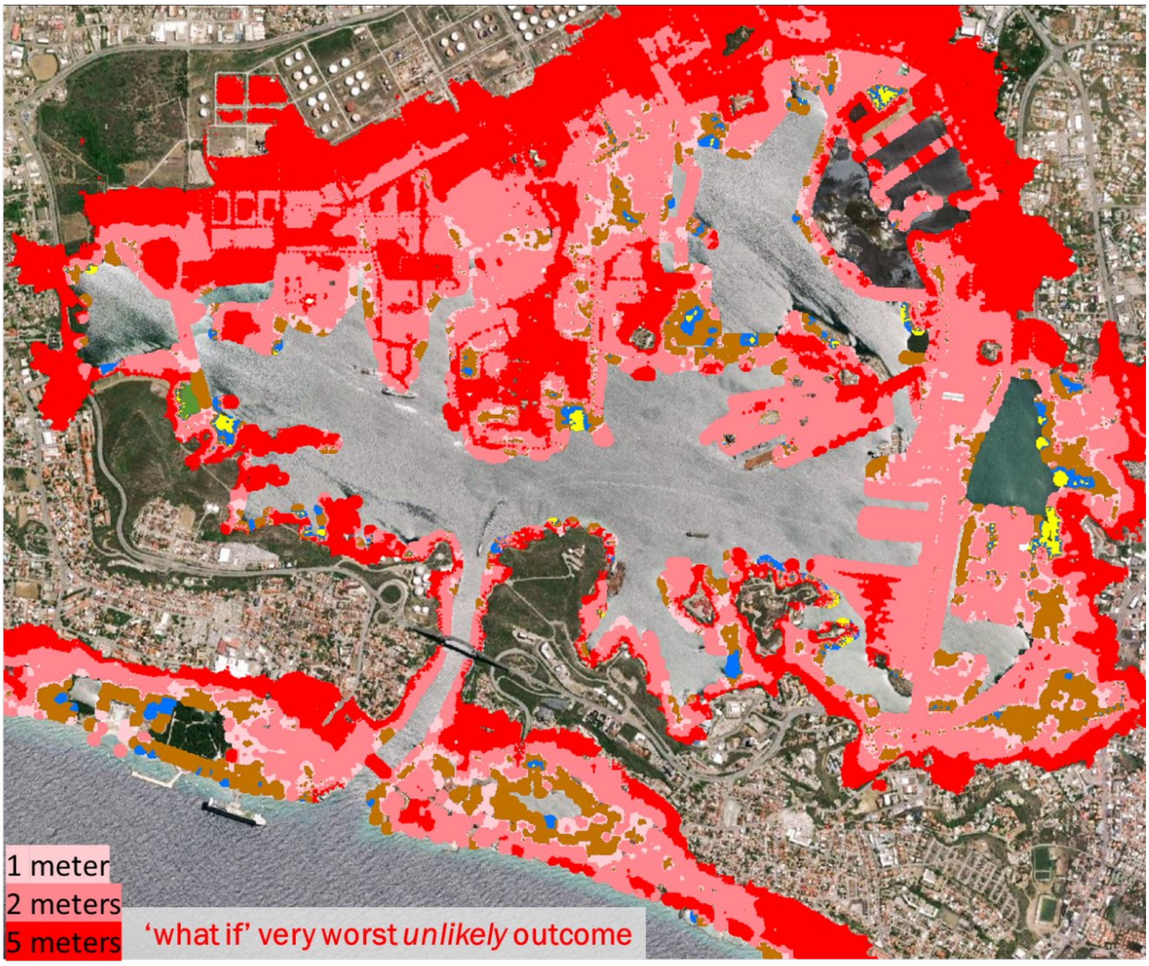


*Figure 18: Areas that could but **unlikely** to be affected by sea-level rise by 2100 and 2150. It shows the locations that could permanently be flooded in case of 1, 2, and 5 meters of sea-level rise.*

For more information about the uncertainties related to the projections of sea-level rise we refer to Annex – Extended hazard assessment.

Storms and tropical cyclones

Storms and tropical cyclones

	Now	2100
	1/100 years causing severe damage	+ more intense with more rainfall

Aruba, Bonaire and Curaçao are on the southern fringes of the hurricane belt (not outside, Figure 19). **Once every four years** a tropical cyclone occurs within a radius of 150 kilometers, but mostly passing to the north of the islands **without causing severe weather**. Historically there is relatively 'minor' wind damage caused to roofs and trees. For Hurricanes Ivan (2004) and Emily (2005), at a distance of ~150km, the potentially damaging tropical storm force winds stayed just north of ABC. Even the immediate effects of major hurricane Hazel, of which the center passed approximately 90 kilometers to the north on October 7, 1954, with maximum sustained winds near the center of 190 km/h, were confined to observed maximum winds of 50 km/h with gusts to 90 km/h, and the damage, an estimated US$ 350.000,-, resulted mainly from flash floods due to heavy rainfall (48 hours averages: approx. 125 mm, Meteorological Department Curaçao, (2018). Waves from tropical cyclones can further lead to damage to the coast of Curaçao and to the harbor. For example, swells from Hurricane Ivan on September 7, 2004, battered several constructions on the ABC coasts. Rough seas during Tropical Storm Joan pounded exposed harbor and beach facilities (Meteorological Department Curaçao, 2018). Furthermore, tropical cyclones can induce storm surges, causing floods due to rising water levels above the normal tidal level. All factors combined, roughly once **every 100 years**, **considerable damage** is experienced by tropical cyclones passing over or just south of the islands.

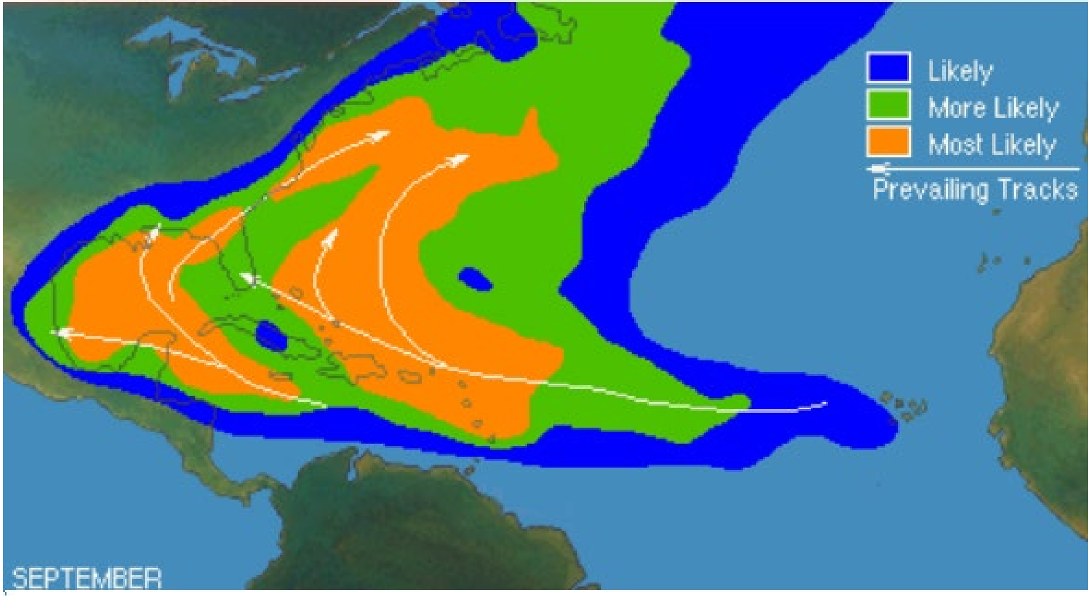


Figure 19: Area of origin and general movement of Atlantic tropical cyclones during September, from Meteorological Department Curaçao, (2018).

In the future, cyclones are projected to become more intense **with more precipitation**, because ocean temperatures rise and because the air can hold more moisture. The tracks of tropical cyclones may reach further north with warmer sea temperatures, but a change in tracks for Curaçao on the southern boundary is not expected. An **increase in the number of cyclones that reach very intense** (Category 4 and 5) is expected because of the increase in magnitude of the cyclones, thus shifting some of the lower category cyclones into the higher categories (https://www.gfdl.noaa.gov/global-warming-and-hurricanes/). A general change in the frequency of tropical cyclones is harder to deduce from climate projections. These models suggest there might be a decrease in the frequency of tropical cyclones, but this projection is related to the El Niño Southern Oscillation (ENSO, see section 3.2). While the projections indicate a El Niño behavior, reducing the number of cyclones, the future might move towards La Niña behavior, as the projections in ENSO lack a skill over the historical period. Thus, the projection for the future can also be questioned (Personal communication Marta and Rein, see Annex C).

Storms and tropical cyclones come with strong wind, waves, and storm surges. In extreme conditions, waves of up to 3 m are to be expected combined with a surge of 0.5 – 0.75 m for Bonaire (Nijsen, 1999). Similar values are to be expected for Curaçao (Werkgroep risico & risicogebieden, 1998), although the specifics for Curaçao and spatial differences over the Island could be further investigated. Future projections of storm surge are predominantly from sea level rise (Bloemendaal, personal communication. See Annex C). The areas prone to temporary floods due to storm surge (~0.5 – 0.75 m) on top of sea level rise (0,86 m) for 2100 (totaling ~1,5 m) are shown in figure 20.

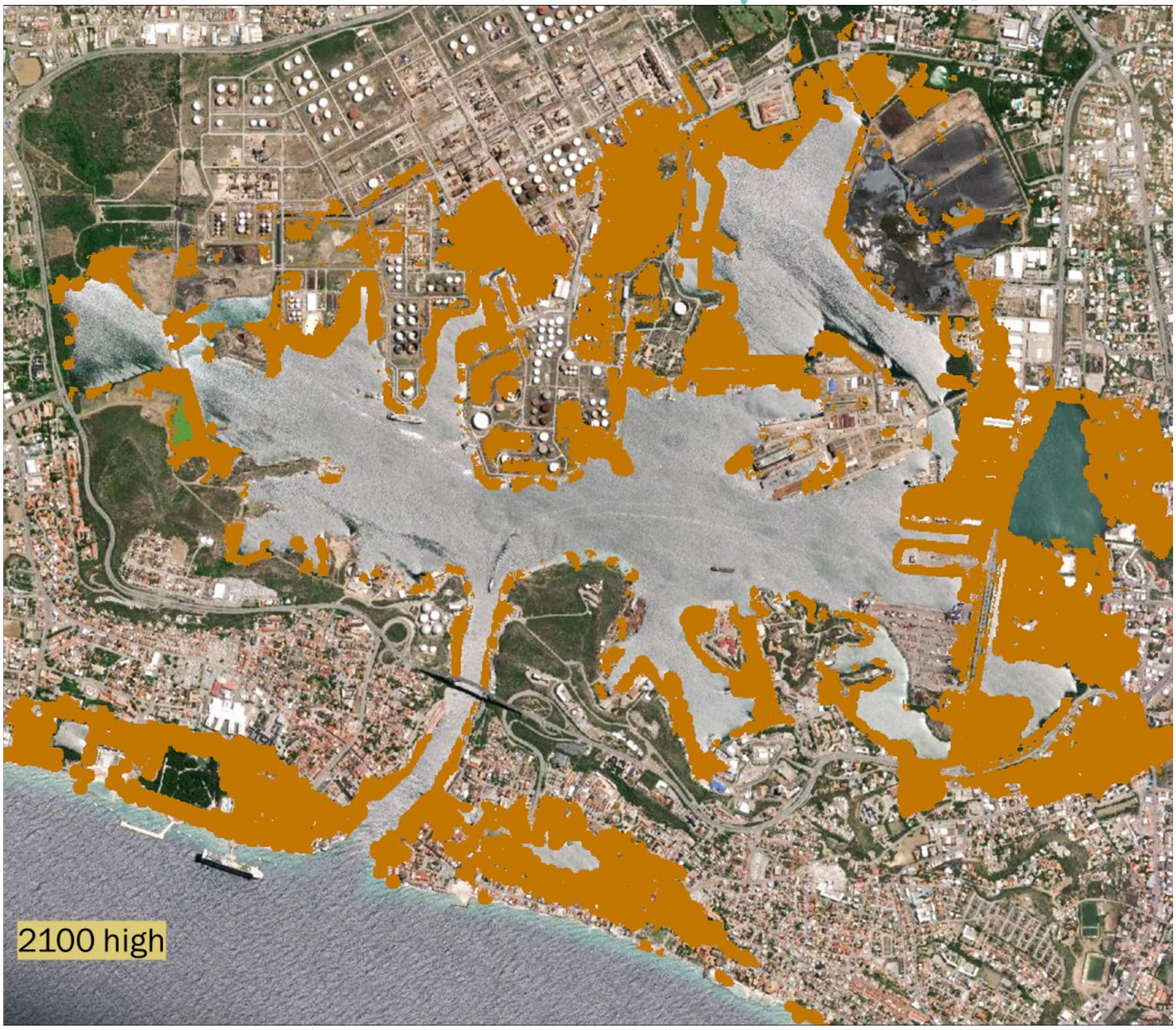


Figure 20: Areas prone to temporal flooding due to storm surges by 2100. These estimates take sea level rise into account.

4. Impacts for CPA and its stakeholders

4.1. Methodology

Climate change impacts are the consequences of climate change for natural and human systems (Burkett et al., 2014). Therefore, an impact assessment seeks to characterize, diagnose and prioritize natural, social and economic impacts. It is typically interdisciplinary, requiring input from a wide range of stakeholders with different expertise and backgrounds. The impact assessment that was carried out for CPA translates the scientific knowledge of climate effects and climate consequences towards insight into opportunities and risks for the different aspects/sectors of all ports and bays in Curaçao. It is an indispensable step towards climate action, because an effective response to the impacts of climate change demands a good understanding of those impacts. In this risk assessment, the impact of climate change on all relevant port aspects/sectors will be analyzed together with the city stakeholders. These are summarized as follows:

1. **Operations** – Refinery including oil handling and storage, dry dock, cargo including container handling, yachting & cruise services, shipping including tugging and bunkering;
2. **Assets** - port structures & buildings, e.g. offices, tanks, terminals, cranes;
3. **Infrastructure** - port infrastructure, e.g. channels, sea locks, roads, bridges, pipelines and powerlines.

A sector-based impacts table has been set up to provide an overview of relevant climate change impacts for CPA (see Annex E for the full table). Based on literature review, a first overview was created of relevant impacts for all hazards that have been identified in the hazard assessment. Based on this sector-based impacts table, impact chains were developed. These chains present a simplified, visual summary of current scientific knowledge of climate effects and climate consequences for CPA. As these chains are simplified representations, they are consequently incomplete. Nevertheless, they offer a powerful starting point for a joint approach in taking climate action.

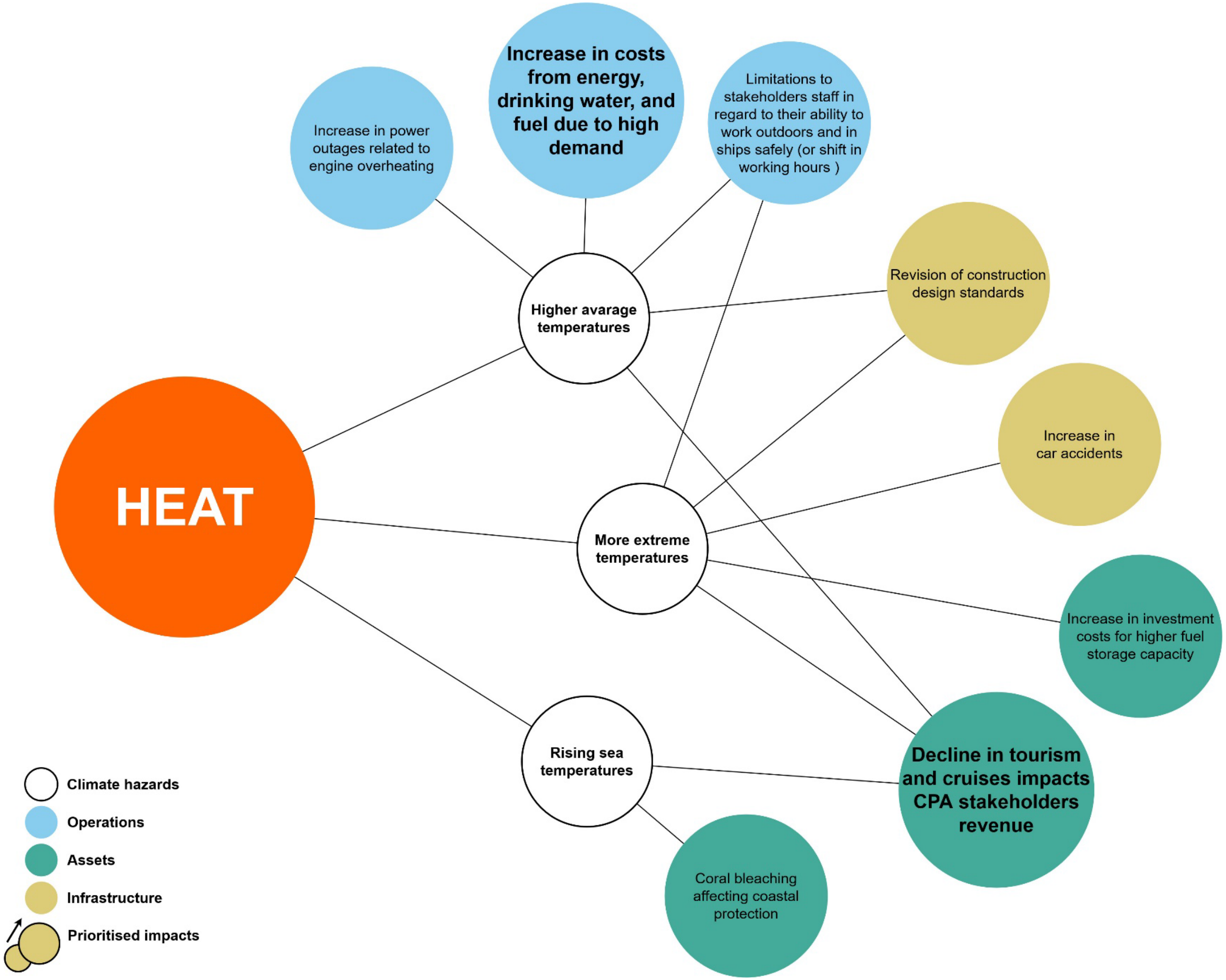
The concept of these impact diagrams was first presented in the Dutch National Climate Adaptation Strategy (2016). The draft impact diagrams serve as a first solid basis to discuss climate impact with local stakeholders. By collectively validating the chains and identifying additional climate impacts, the final climate impact diagrams are co-created. To ensure ownership and completeness, discussions should focus on definitions, relations between hazards and impacts and potentially missing impacts.

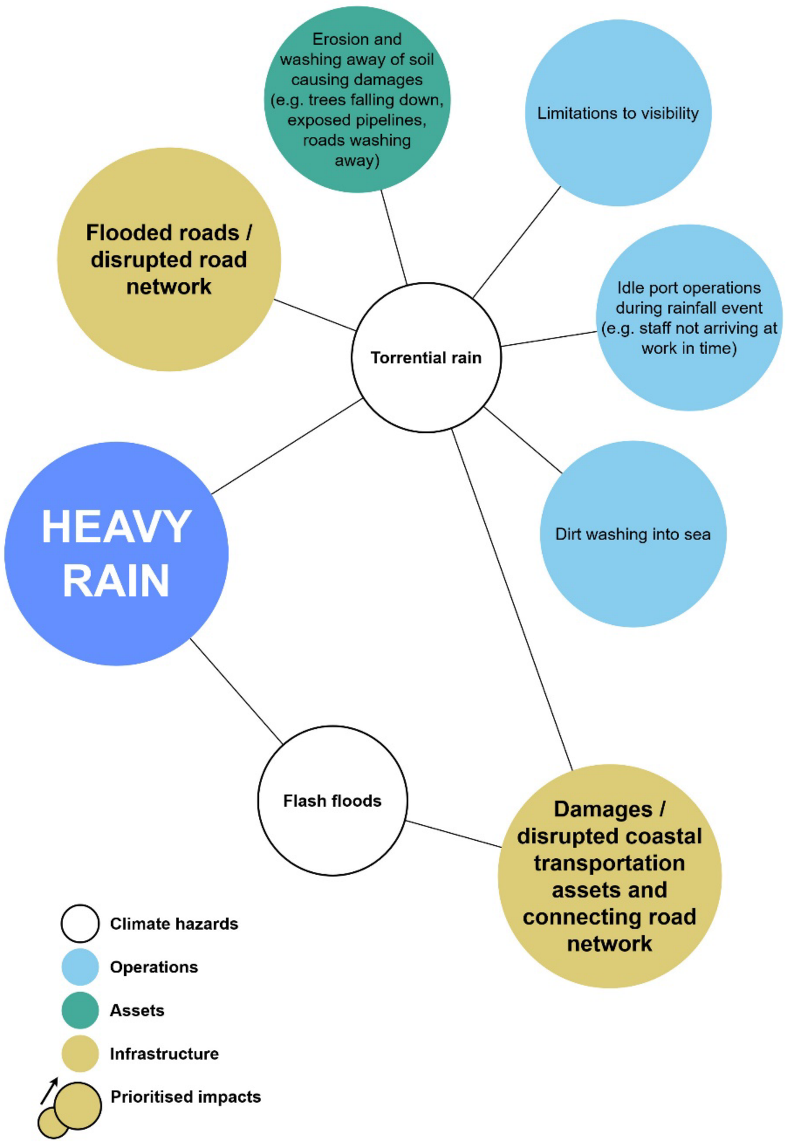
Separate from the impact assessment, an assessment of the vital port aspects/sectors has been carried out, in order to get information on which parts of the port need the most attention when defining a strategy for climate change adaptation. For defining which components of the port are essential the following basic starting points have been used:

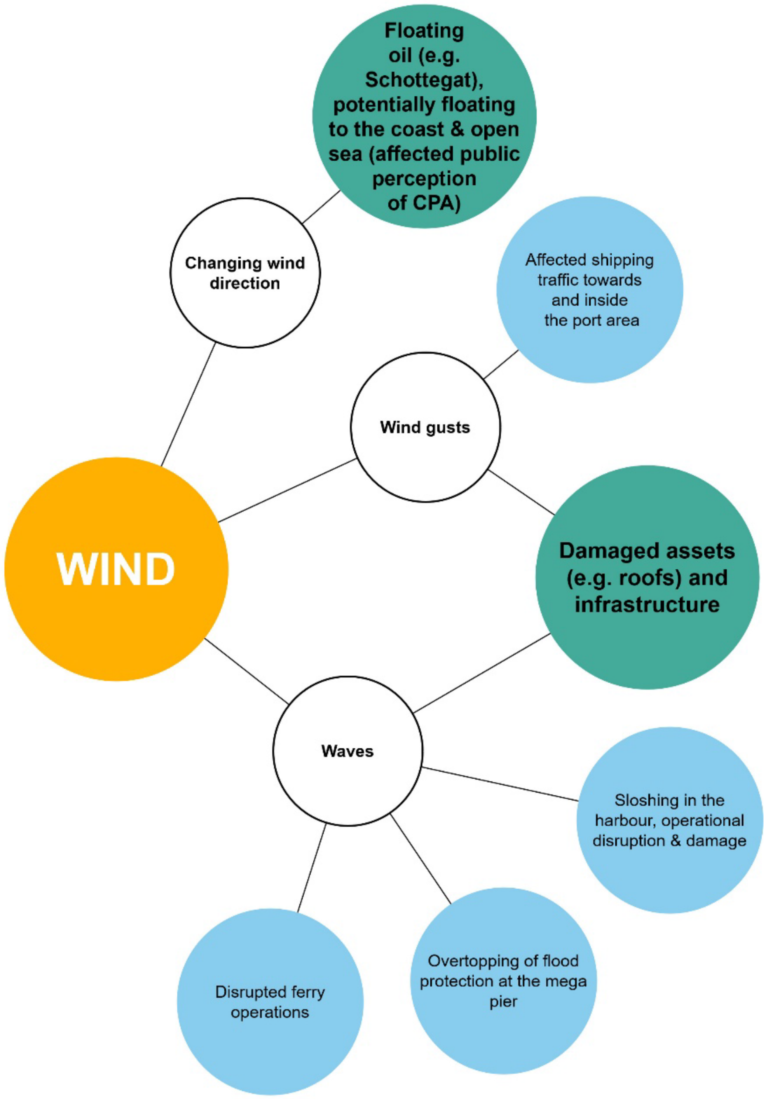
- What is needed by emergency services in case of disaster;
- What disrupts daily business;
- What has a high value (for the economy).

A first overview of the vital operations, assets and infrastructure was created based on local knowledge of the area and was checked by CPA. During the workshop of November 10, 2022 these maps of vital operation, assets and infrastructure were presented to the stakeholders and completed during a break-out session by them.

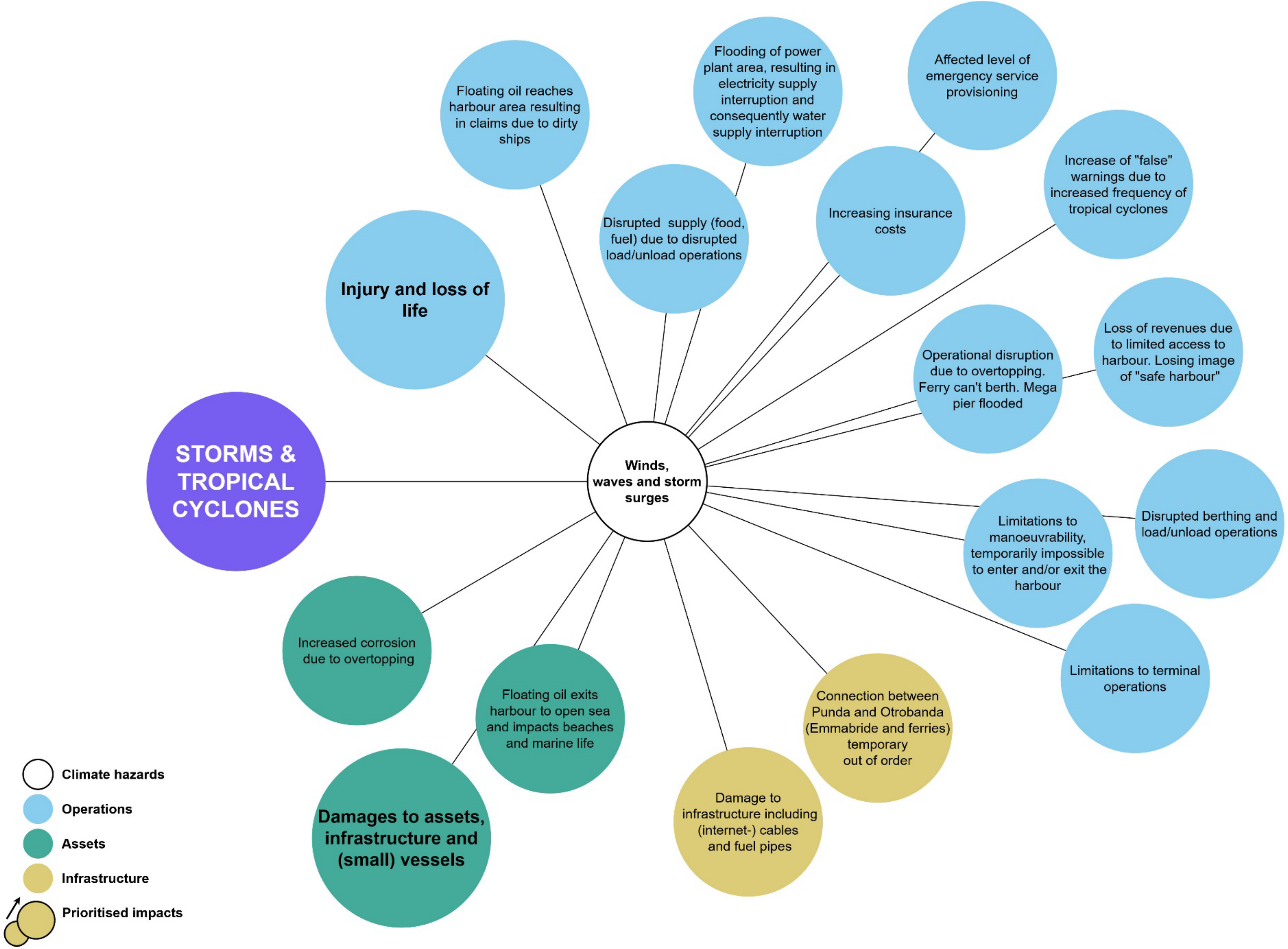
4.2. Validated impact chains




Erosion and washing away of soil causing damages (e.g. trees falling down, exposed pipelines, roads washing away)
Limitations to visibility
Flooded roads / disrupted road network
Torrential rain
Idle port operations during rainfall event (e.g. staff not arriving at work in time)
HEAVY RAIN
Dirt washing into sea
Flash floods
Damages / disrupted coastal transportation assets and connecting road network
Climate hazards
Operations
Assets
Infrastructure
Prioritised impacts


Floating oil (e.g. Schottegat), potentially floating to the coast & open sea (affected public perception of CPA)
Changing wind direction
Affected shipping traffic towards and inside the port area
Wind gusts
WIND
Damaged assets (e.g. roofs) and infrastructure
Waves
Sloshing in the harbour, operational disruption & damage
Disrupted ferry operations
Overtopping of flood protection at the mega pier


SEA-LEVEL RISE
Operational disruption due to siltation or scouring problems
Affected surrounding community and environment
Affected logistics
Affected wave height pattern & agitation within the harbour
Tourism revenue decrease due to loss in sandy beaches
Quays, jetties, and breakwaters may require redesigning and/or strengthening
New equipment and facility maintenance needs
Revision of construction design standards
○ Climate hazards
● Operations
● Assets
● Infrastructure
Prioritised impacts


STORMS & TROPICAL CYCLONES
Winds, waves and storm surges
Injury and loss of life
Floating oil reaches harbour area resulting in claims due to dirty ships
Disrupted supply (food, fuel) due to disrupted load/unload operations
Flooding of power plant area, resulting in electricity supply interruption and consequently water supply interruption
Increasing insurance costs
Affected level of emergency service provisioning
Increase of "false" warnings due to increased frequency of tropical cyclones
Operational disruption due to overtopping. Ferry can't berth. Mega pier flooded
Loss of revenues due to limited access to harbour. Losing image of "safe harbour"
Limitations to manoeuvrability, temporarily impossible to enter and/or exit the harbour
Disrupted berthing and load/unload operations
Limitations to terminal operations
Connection between Punda and Otrobanda (Emmabride and ferries) temporary out of order
Damage to infrastructure including (internet-) cables and fuel pipes
Floating oil exits harbour to open sea and impacts beaches and marine life
Increased corrosion due to overtopping
Damages to assets, infrastructure and (small) vessels
Climate hazards
Operations
Assets
Infrastructure
Prioritised impacts

The table below shows the prioritized impacts based on stakeholder input during the workshop.

Theme	Hazard	Impact	Prioritised
Storms & tropical cyclones	*Waves & storm surges*	**Damages to assets infrastructure and vessels**	15
Heavy rain	*Flash floods, erosion*	**Damages / disrupted coastal transportation assets and connecting road network**	10
Sea-level rise		**Affected logistics**	8
Wind	*Wind gusts & waves*	**Damaged assets (e.g. roofs) and infrastructure**	6
Heat	*Rising sea and air temperatures, more temperature extremes*	**Affected revenue due to tourism decline**	6
Heat	*Higher average & extreme temperatures*	**Increase in energy costs & fuel**	5
Sea-level rise		**Affected surrounding community and environment**	5
Sea-level rise		**Quays, jetties, and breakwaters may require redesigning and/or strengthening**	3
Storms & tropical cyclones	*Winds, waves, storm surges*	**Injury and loss of life**	3
Sea-level rise		**Tourism revenue decrease**	2
Sea-level rise		**Revision of construction design standards**	2
Heavy rain	*Torrential rain*	**Floods roads / distupted road network**	2
Wind	*Changing wind direction*	**Floating oil, potentially leaving port area**	2

4.3. Vital parts assessment

As indicated in paragraph 2.1, the following ports/harbors are included in the study: Willemstad (main port), Bullenbaai (oil terminal with 5 jetties), Caracasbaai (2 jetties for longer berth periods), Fuikbaai (bulk quay).

The vital parts assessment is mainly focused on the Willemstad port since most port/harbor related vital parts are in this area. The Willemstad port comprises several bays (Figure 21) and over 20 jetties and quays (Figure 22).

Figure 21: All bays in and around Willemstad.

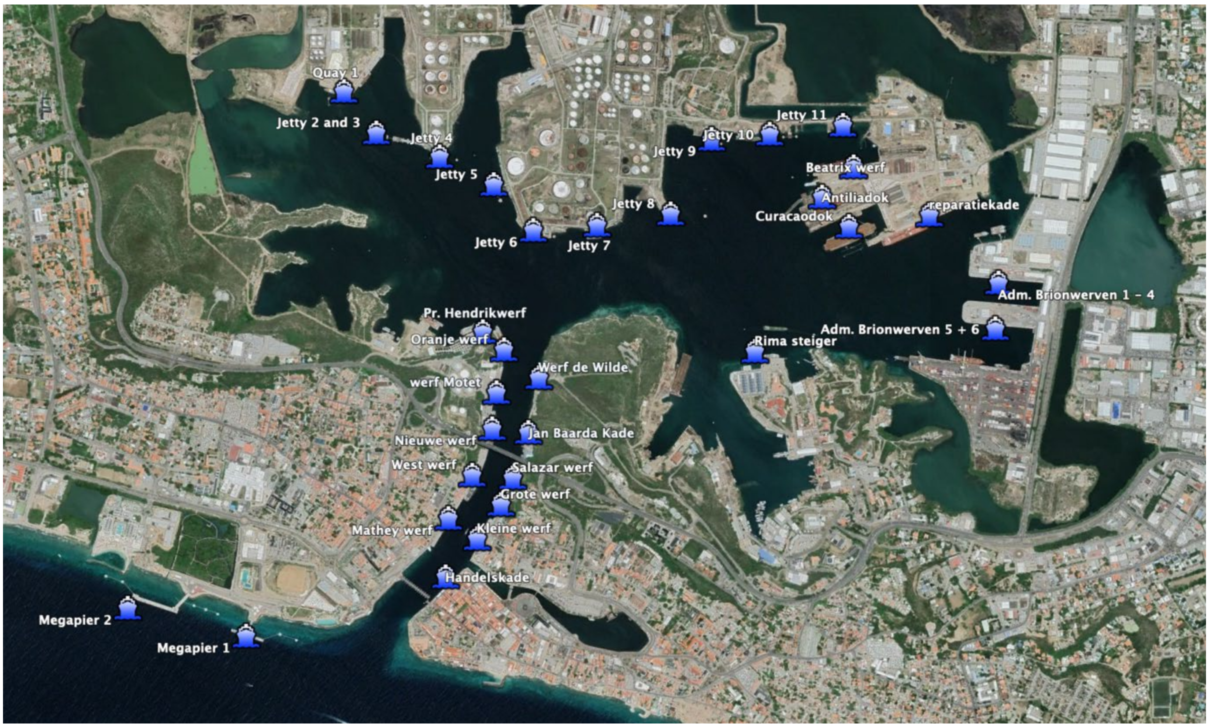


Figure 22: All jetties and quays in and around Willemstad port.

There are 4 large business areas with their own assets, infrastructure and operations in the Schottegat area. These are the refinery (RdK/CRU), the drydock (Damen Ship Repair), the naval base and the container harbor (CPS). Figure 23 shows the location of these business areas.

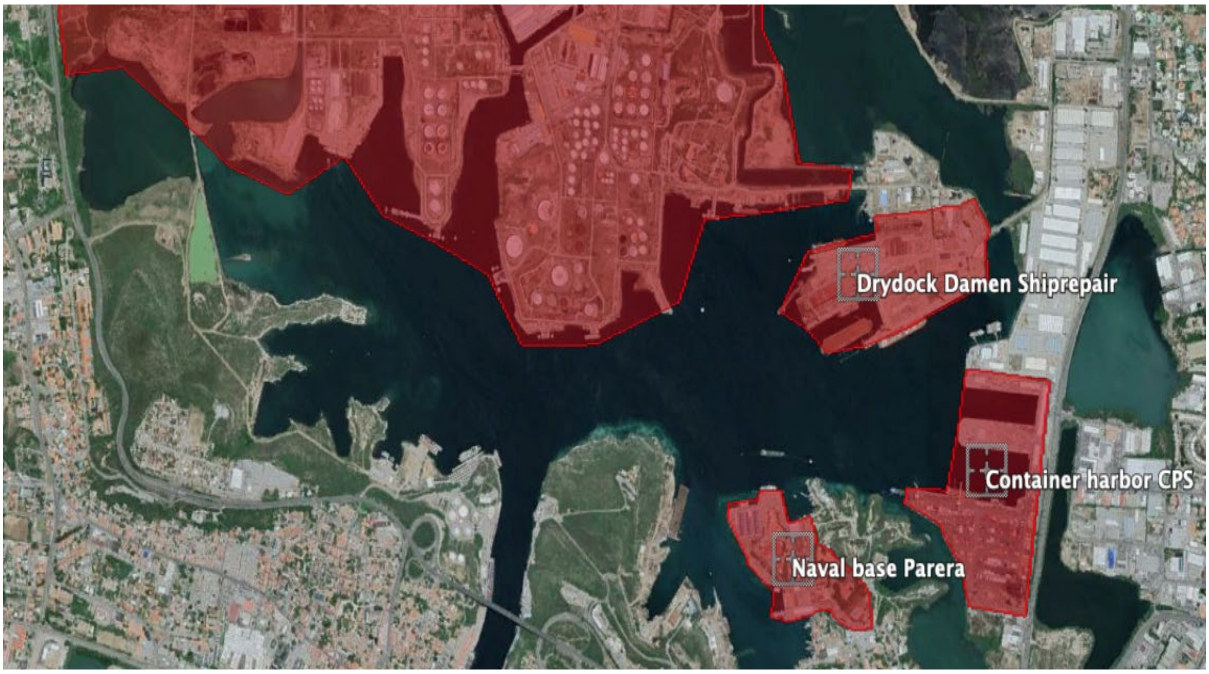


Figure 23: Indication of location of the 4 large business areas within Willemstad port.

Vital operations

The following vital operations take place in the Willemstad port: piloting, tugging, vessel control, bunkering, loading/unloading containers, oil transshipment. The pilot organization (Curaçao Pilot Organization, CPO) is located at the Motet Wharf and the towing company (Kompania di Tou Kòrsou, KTK) is located at the Jan Baardakade. Vessel control is done from the Vessel Control Center (VTCO) at Fort Nassau. Bunkering takes place at the Nieuwe Wharf. Container loading and unloading takes place at the Adm. Brion Werven by the company Curaçao Port Services (CPS), oil transshipment takes place at the jetties of the refinery and at the Pr. Hendrik Wharf (Curoil). Figure 24 shows the vital operations in the Willemstad port area.

During the workshop the following vital operations were added: tour operators at the Mega Piers, quay 1 of the refinery for import of lpg and gasoline for local use (Curaçao and Bonaire) and jetties 4 and 8 of the refinery for fuel import for the power plants of Aqualectra and for jet fuel for the airport. These added items are also presented in figure 24 (in green).

Figure 24: Indication of location of vital operations within Willemstad port. Operations in green were added during the workshop.

Vital assets

The vital assets within the Willemstad port are the two Mega Piers, the jetties of the refinery, the quays and cranes of the container harbor, the docks and workshops of Damen Shiprepair, the offices of CPA and the Scharloo development project. The locations of these assets are shown in Figure 25. The jetties at Bullenbaai and Caracasbaai are considered vital assets as well.

During the workshop, the following vital assets were added: all power plants of Aqualectra (MAN diesel plant at the refinery and Dokweg 1, 2A and 2B powerplants at the Dokweg), the pontoon bridge (Koningin Emmabrug), the Koningin Julianabrug and the tugboats of KTK, tour operators at the Mega Piers, all fuel imports for local use, Customs (indicated as vital for clearing vital import products), the Royal Navy and the Coast Guard and the CPA maintenance site (for maintenance of tugboats, ferries, pilot boat and the pontoon bridge). All of these added items are presented in figure 25 (in green).

Figure 25: Indication of vital assets within Willemstad port. Assets in green were added during the workshop.

Infrastructure

The main vital infrastructure objects are: The pontoon bridge (Koningin Emmabrug), the Koningin Julianabrug, the ferries between Punda and Otrobanda, the Emancipatie Boulevard and Schottegatweg Zuid, the Vessel Control Center (VTCO), the tugboats from KTK, the pilot boats from CPO, the bunkering infrastructure at the Motet Wharf, and the bunkering infrastructure at both Mega Piers. Figure 26 shows the locations of these infrastructures.

During the workshop the following vital infrastructures were added: the hospital, Curaçao Medical Center (CMC) including the access road; the Curoil tanks at Otrobanda; the oil and gas jetties at the refinery area since they are vital for the import of oil and gas for island use.

Figure 26: Indication of vital infrastructure within Willemstad port. Infrastructures in green were added during the workshop.

4.4. Vulnerable hotspots

During the workshop the participants were asked to indicate their experience with areas vulnerable to climate change in the Willemstad port area. An area can be considered vulnerable to excessive heat, flooding due to excessive rain, excessive wind, flooding due to sea level rise or storm or tropical cyclone. Figure 27 shows the results of this vulnerable hotspot assessment.

Figure 27: Results of the vulnerable hotspot assessment.

4.5. Future development

Future developments are also important for the impact assessment. In the CPA Master Plan for St. Anna Bay, four areas under CPA administration are proposed for new developments. These areas include Scharloo and Kleine Wharf; Otrobanda's Mathey Wharf; the Waaigat lagoon; and properties immediately north of the Koningin Juliana Bridge. In total these properties account for over 16 hectares of shoreline and submerged lands. The following text and pictures are taken from the CPA website.

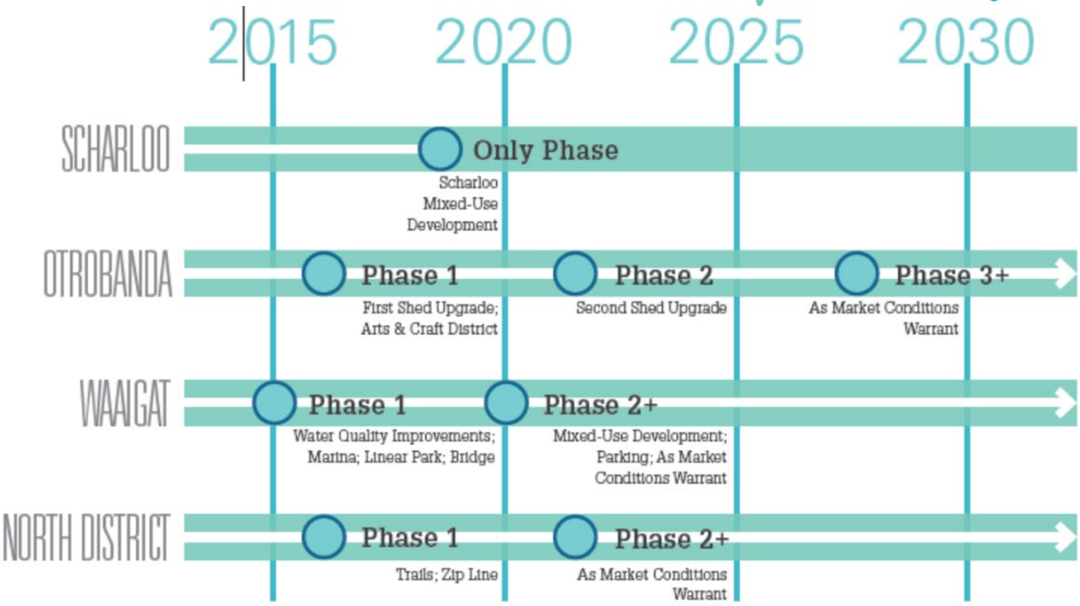


Figure 28: Planning for future developments.

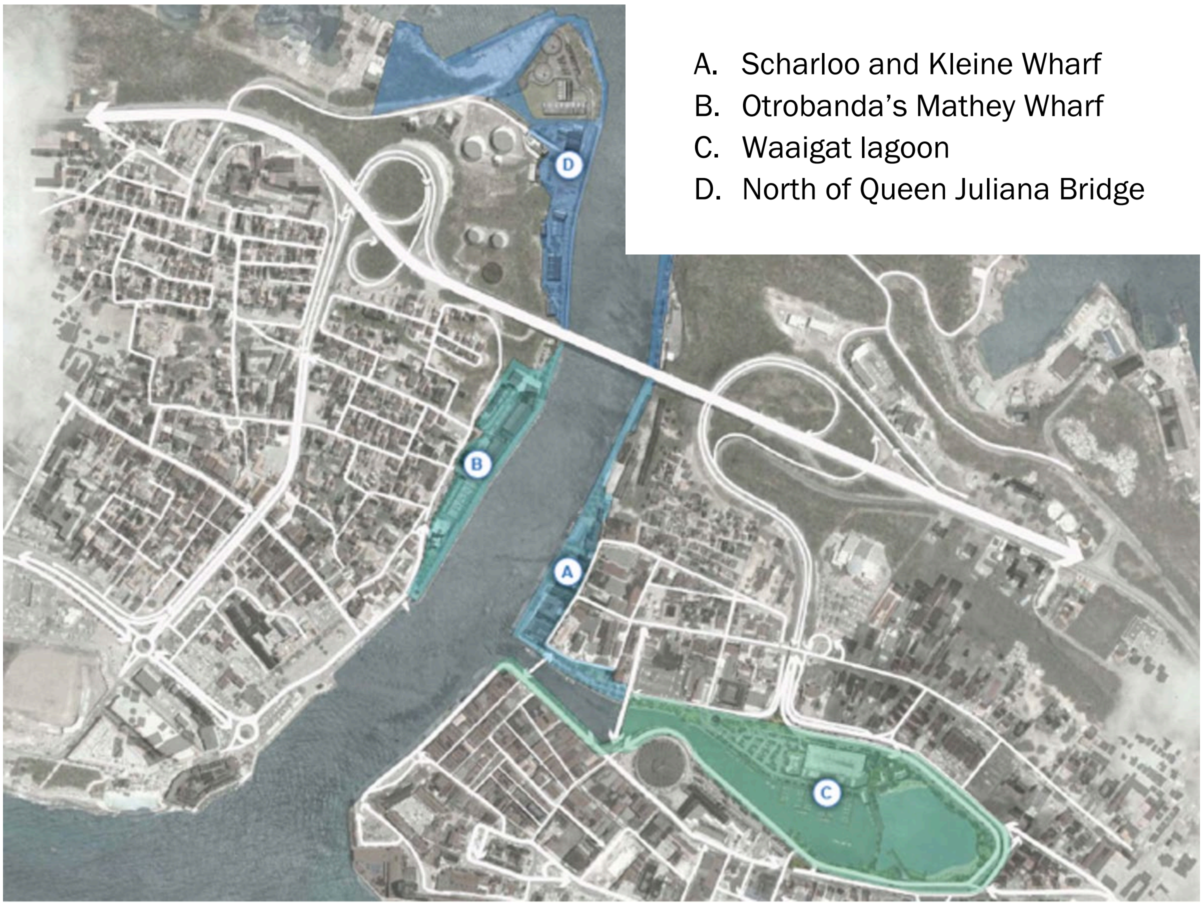


Figure 29: Overview of areas proposed for new development in the Master Plan for St. Anna Bay.

The Scharloo project, as described in the Master Plan, consists of a sequence of urban blocks along a new waterfront esplanade. A ground floor restaurant, entertainment and small retail establishments give way to residential and hospitality uses above. The entirety of the district is linked by new parks and pedestrian ways for the public to enjoy.

Figure 30: Artist impression of Scharloo project.

The Otrobanda plan includes urban cultural space with food, retail, small businesses, arts and performance venues housed in a repurposed Mathey Wharf cargo shed. Mathey Wharf continues its use as a key maritime berth, welcoming cruise and other visiting ships. When vessels are not present, the waterfront and hardscape plazas open to provide a unique outdoor and public venue for concerts, performances and social gathering.

Figure 31: Artist impression of Otrobanda project.

The Waaigat project concentrates in the first place on solving the area's water quality issues. This includes redevelopment of the lagoon's edge and installation of new infrastructure to eliminate wastewater and storm water release. Following this, landside improvements are introduced, inclusive of a linear park, lagoon bridge, small marina and a mixed-use development supporting restaurant, office, residential and civic uses along with expanded parking. A portion of the lagoon could be transformed into an iconic, urban beach linked to the vibe and spirit of Punda and Pietermaai.

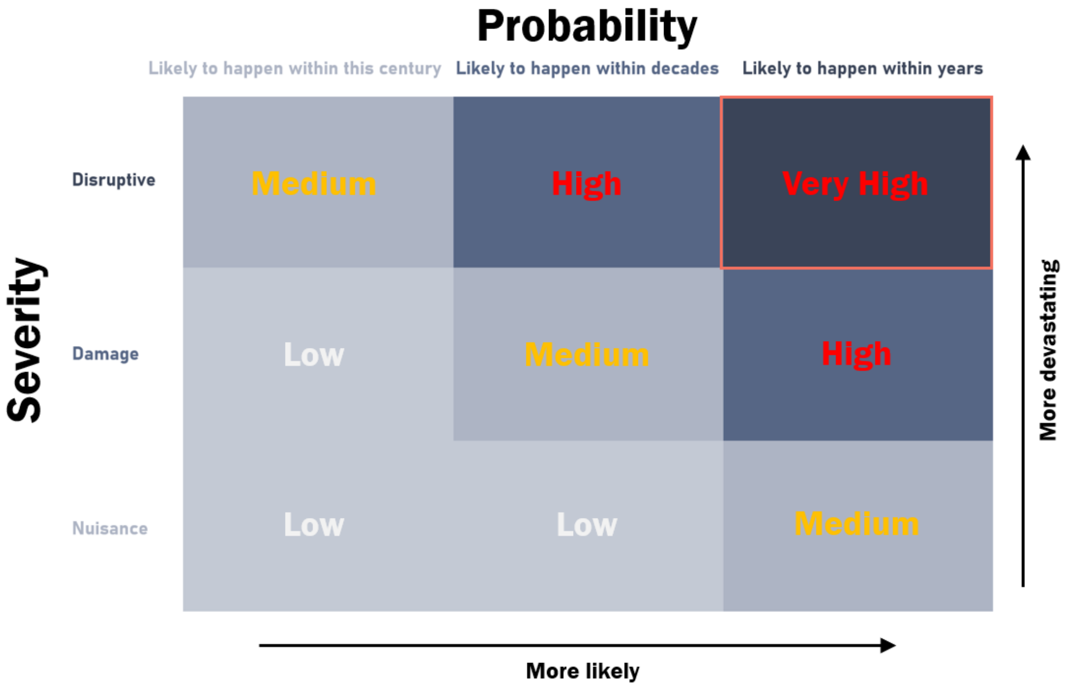
Figure 32: Artist impression of Waaigat project.

To the west, the plan includes an upgrade site infrastructure making it capable of safely accommodating fuel ship activities while also expanding the potential for this area to provide a logistical nexus for industries supporting the offshore energy sector. To the east, the Curaçao Ports Authority site is upgraded to house a greater number of maritime office users as well as providing recreational facilities.

5. Key climate risks

5.1. Methodology

In order to identify the key climate risks for CPA, a risk matrix was used to assess severity and probability of the priority impacts. Figure 33 provides an example.

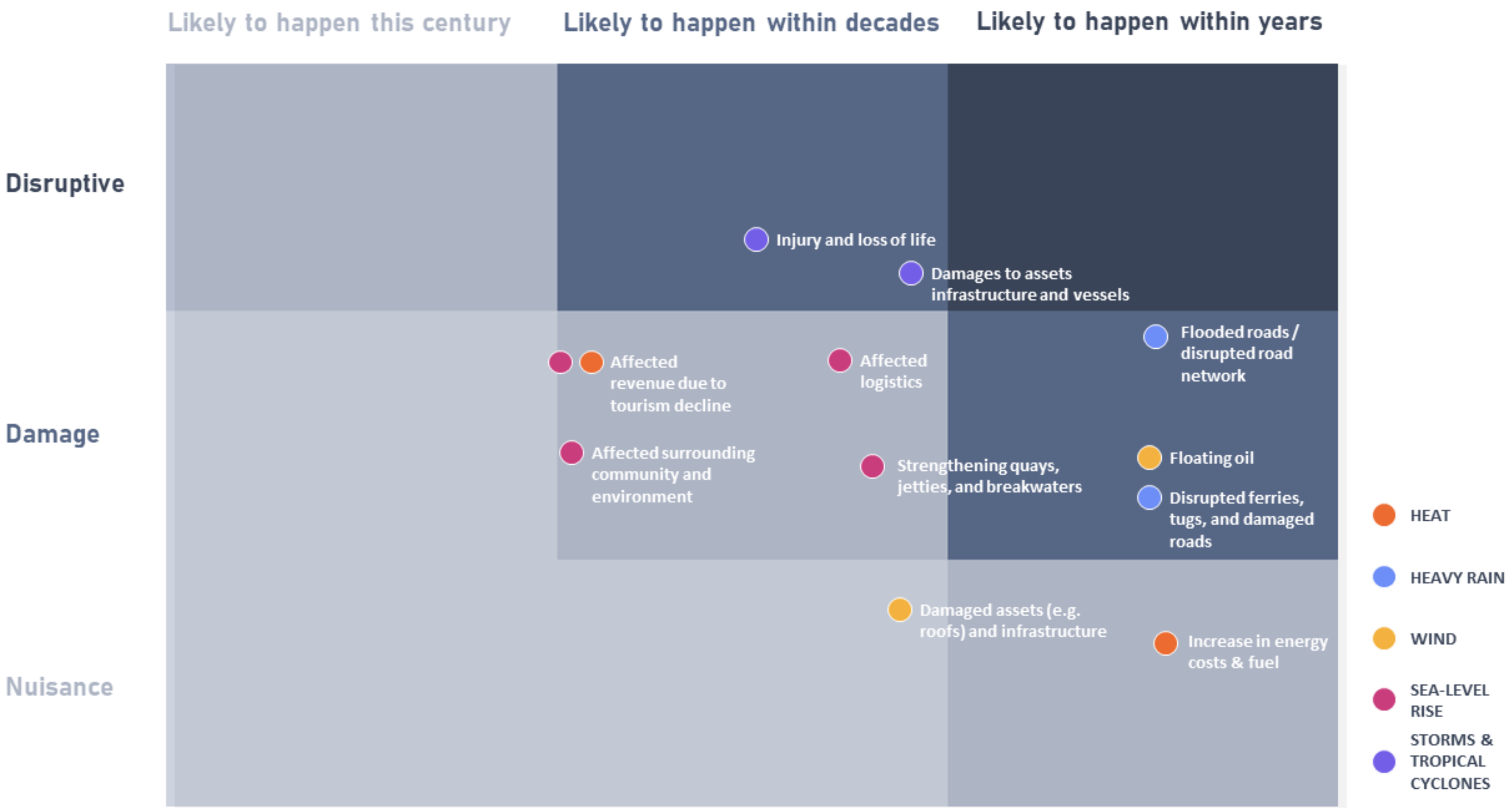


	Likely to happen within this century	Likely to happen within decades	Likely to happen within years
Disruptive	Medium	High	Very High
Damage	Low	Medium	High
Nuisance	Low	Low	Medium

Figure 33: example of a climate risk matrix.

Severity and probability are on the X- and Y-axes of this matrix and are used for the purpose of performing action prioritization. This step is based on expert judgement. Impacts that fall in the top right quadrant present the highest climate risks as these impacts are the most likely to happen, and the most devastating when they do happen.

5.2. Overview of key climate risks



6. Roadmap with possible follow-up steps

6.1. Research opportunities

Hazard research opportunities (identified by us)

This section describes the research opportunities which could improve the hazard analysis. The section is sorted by the hazards that relate to the key risks for CPA and its stakeholders: heavy rain and storms & tropical cyclones first; then sea-level rise and wind; followed by heat. Note that drought is not taken into account here as droughts are outside the scope of this study for CPA. However, drought is an important topic to take into account when taking a wider look at climate impacts for Curaçao.

For heavy rainfall, a research question is **how to map the effects of extreme sub-daily rainfall** and flash floods? We mostly rely on the historical information because the (‘convective’) processes relevant for heavy rainfall are not well calculated (‘resolved’) by climate models. There is a research opportunity to update the historical (CliVar) analysis with most recent measurements and expanding to more parameters. It would be interesting to study how historical data could provide us an estimate of future rainfall in addition to climate model scenarios.

High-resolution (‘convective-permitting’) climate model simulations would be an interesting resource to further our understanding of future sub-daily rainfall extremes (Dale, 2021; Fowler, Wasko and Prein, 2021). The Delft-Fews system used for flood simulations probably could benefit from an update, including an update in the underlying hydrological and hydraulic models (Personal communication Albrecht Weerts, Expert Hydrology Deltares). With respect to near real time flood forecasts, including bias corrected nowcasting and bias corrected radar rainfall data could be an interesting research avenue (Imhoff, 2022).

The question whether there is a **change in the season** for storms and tropical cyclones to occur was raised during the workshop. Furthermore, a research gap is the uncertain change in the frequency of storms and cyclones. This is an active topic of research deserving wide research attention because of the vast implications (Knutson *et al.*, 2020; Roberts *et al.*, 2020; Bloemendaal *et al.*, 2022). For storm surges, a first cautionary estimate of areas prone to temporary floods during storms and cyclones was mapped. Future work could **model storm surges incorporating detailed information** on e.g., water depths for each of the harbors. The combination of extreme precipitation with elevated surge waters is another knowledge gap that requires further study.

For sea-level rise, a knowledge gap is the **validation of historical trends** from satellites to observations. For sea-level data from CPA (Schottegat) and Meteo Curaçao (Bullenbaai), it is recommended to regularly measure (check) the local level benchmark and tie it into the Curaçao NMP level. Records for these stations were not long enough to determine and validate long-term trends. In the earlier days (1960-1995) analogue water level measurements have been executed as well. Finding and validating these measurements would prove a valuable addition to the assessment of historical sea-level rise. In addition, measurements of groundwater fluctuations help understand permeability of the soil useful to evaluate adaptation options. Another future opportunity is long-term and spatial variation in plate tectonic movement of Curaçao.

For trends in wind speed and wind direction, a quality check of historical data is an important step. In general, resources for the Meteorological Department Curaçao to strengthen their **capacity to maintain, validate, and digitize measurements** are imperative for all of the hazards. For mapping hazards and impacts, **accurate elevation maps** (Digital Elevation Model, DEM) and other base maps (land use, geology, etc.) are crucial.

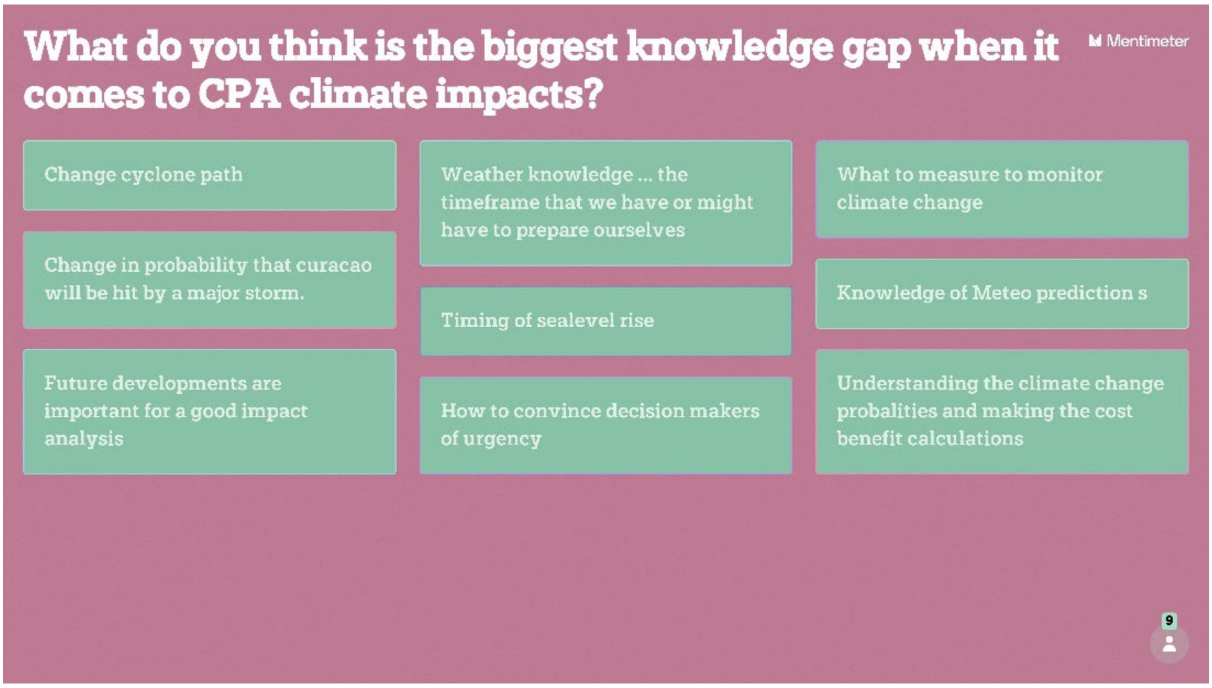
Spatial information on thermal comfort is the largest knowledge gap for heat. Our first exploratory assessment using a heat index did not yet include wind or sunshine, and, therefore, requires further study and validation. It, furthermore, only shows heat for Hato while large spatial differences can occur. For the harbor, especially in locations with a lot of asphalt that are shielded from wind, locally heat can be much worse.

Impact knowledge gaps

During the workshop, several knowledge gaps related to CPA's climate impacts were identified:

- An in-depth analysis of cyclone paths and future trends related to these paths, as well as the (changing) probabilities for cyclones and storms.
- An understanding and selection of indicators for monitoring. By monitoring changes in climate, sea level, hydrology, and land use, it becomes clear whether it is necessary to adjust CPA's decisions and strategies. Based on monitoring information, decisions can be made to shift the focus and pace of adaptation action.
- An in-depth analysis of historical and projected sea-level rise for Curaçao, using for example higher-resolution regional models.
- An assessment of climate change impacts on future developments in and around the ports area.
- An analysis of costs and benefits of climate change. Insight in costs and benefits helps to assess and prioritize options and allocated financial resources.

Figure 34 provides an overview of all gaps that were identified by the workshop participants.



What do you think is the biggest knowledge gap when it comes to CPA climate impacts?

Change cyclone path

Change in probability that curacao will be hit by a major storm.

Future developments are important for a good impact analysis

Weather knowledge ... the timeframe that we have or might have to prepare ourselves

Timing of sealevel rise

How to convince decision makers of urgency

What to measure to monitor climate change

Knowledge of Meteo prediction s

Understanding the climate change probalities and making the cost benefit calculations

Figure 34: Results of online poll among workshop participants.

CPA opportunity: filling data gaps

The sections above highlight the importance of ‘base data’. It is recommended to maintain, validate, and digitize measurements for sea level data (from CPA, Schottegat and MDC, Bullenbaai), as well as meteorological variables (from MDC). For sea level data, it is recommended to regularly measure (check) the local level benchmark and tie it into the Curaçao NMP level. CPA could also start tracking impacts. From this report it becomes clear that many types of impacts have already been experienced (see section 4.3). Information about impacts that occur are very useful for monitoring and developing a climate adaptation strategy. It is recommended to systematically describe impacts that are observed: what damage has occurred when and due to what? Finally, it is recommended to monitor the state of knowledge every 5 years.

6.2. Adaptation goals & targets

The outcomes of the climate risk assessment and the overview of the key climate risks can be used to work towards adaptation goals and targets for CPA. Creating an adaptation vision, and setting specific adaptation goals and targets, will help CPA with planning, decision making and with prioritizing actions. Together, these can act as:

- an anchor point to any strategic climate action plan;
- a direction for future climate adaptation decision-making;
- guidance for prioritizing adaptation actions and Monitoring, Evaluation and Reporting.

Figure 35 shows a conceptual overview of a Vision, Goals, Targets and Actions-Network, explaining the relationship between these components. This example was developed for a city.

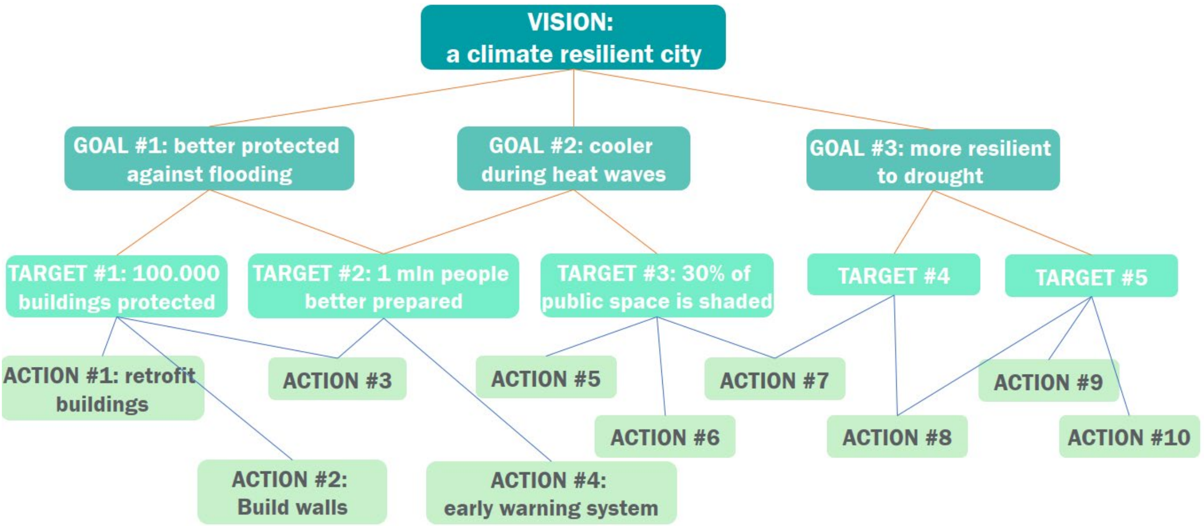


Figure 35: Concept of a Vision, Goals, Targets and Actions-Network. Based on an approach that was developed for the global city network C40 Cities.

As Figure 35 shows, an adaptation vision can act as the overarching statement from which adaptation goals, targets and actions can be identified. Determining an adaptation vision is a challenging task. Using the results from the climate risk assessment, CPA could validate and co-produce a climate adaptation vision statement and validate and co-determine clear adaptation goals and targets.

Building upon an overarching adaptation vision for CPA, specific adaptation goals can be identified. The goals can be directly linked to the key climate risks that were identified and validated during this project. An adaptation goal can be formulated by positively framing the key risks (if the risk is frequent flooding, the goal will be less floods or more flood protection). Targets make goals concrete and measurable. Targets should be (semi-) quantitative. These can be:

- output-related (e.g. number of trees planted);
- outcome-related (e.g. 4 degrees colder during a heatwave);
- impact-related (e.g. #10.000 people protected).

Figure 36 presents an example of a Vision, Goals, Targets and Actions-Network, that was developed for Jakarta, Indonesia.

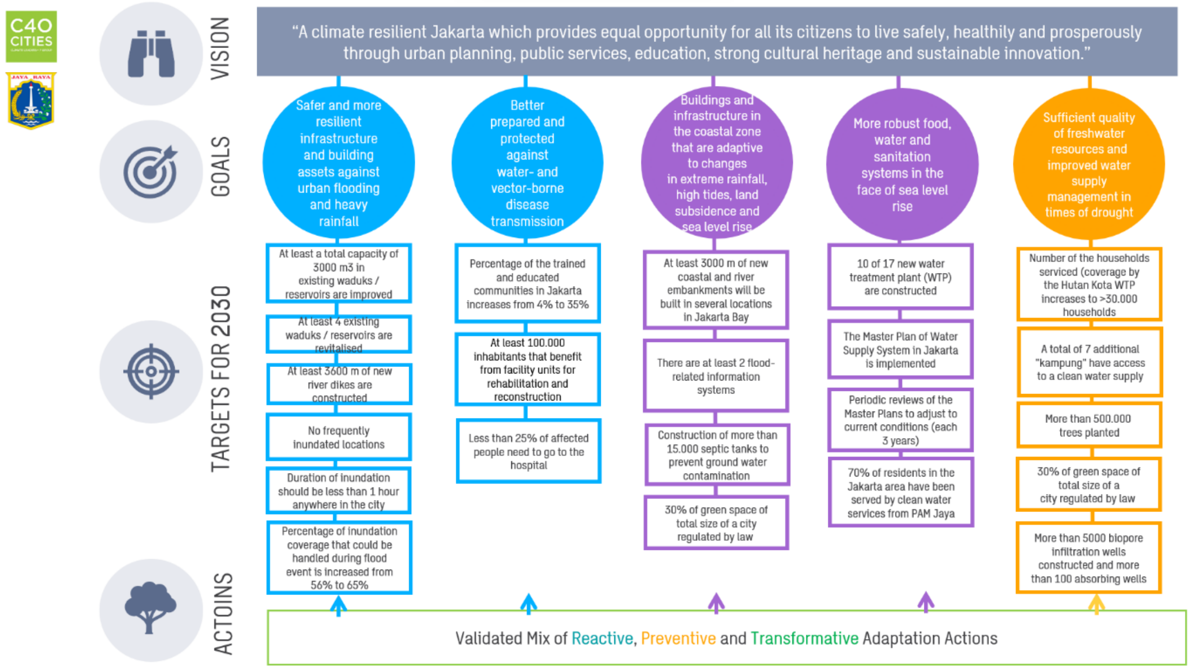


Figure 36: Example of an adaptation vision and underlying adaptation goals & targets, developed for Jakarta, Indonesia.

Adaptation goals and targets form the basis for identifying suitable adaptation actions to reduce climate impacts, finding a balanced mix based of reactive, preventive, and transformative strategies.

6.3. *Identifying adaptation actions*

Adaptation actions can be aimed at (Climate-ADAPT, 2022):

- **accepting** the impacts, and bearing the losses that result from risks (e.g. managing retreat from sea level rise);
- **off-setting** losses by sharing or spreading risks (e.g. through insurance);
- **avoiding or reducing** exposure to climate risks, by implementing reactive, preventive or transformative adaptation measures (e.g. building new flood defenses);
- **exploiting** new opportunities (e.g. engaging in a new activity, or changing practices to take advantage of changing climatic conditions).

Adaptation planning is an iterative process that is driven by various motivations and that involves a variety of actions. Three broad categories of complementary adaptation strategies can be distinguished: reactive, preventive, and transformative adaptation (Figure 37; Boon *et al.*, 2021).

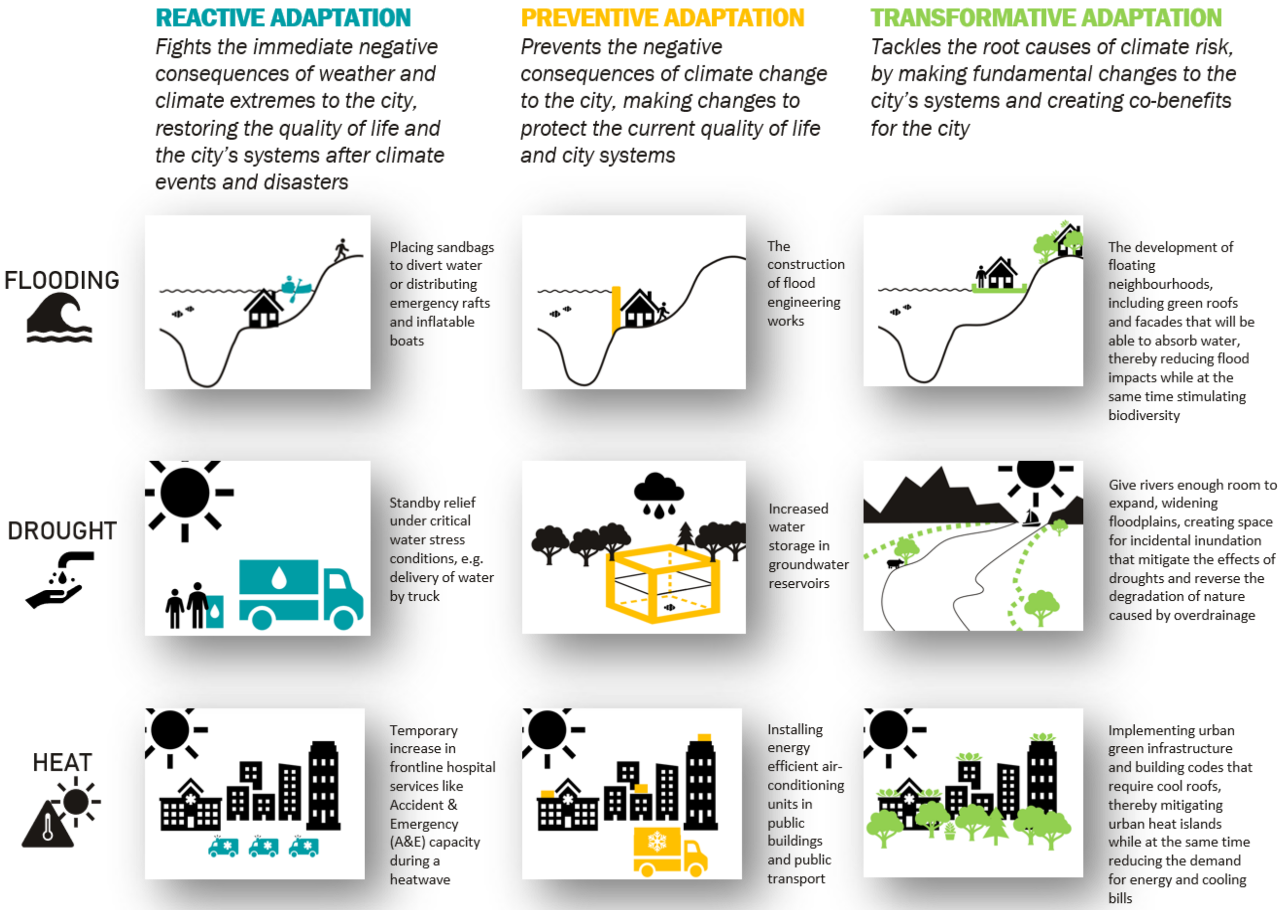
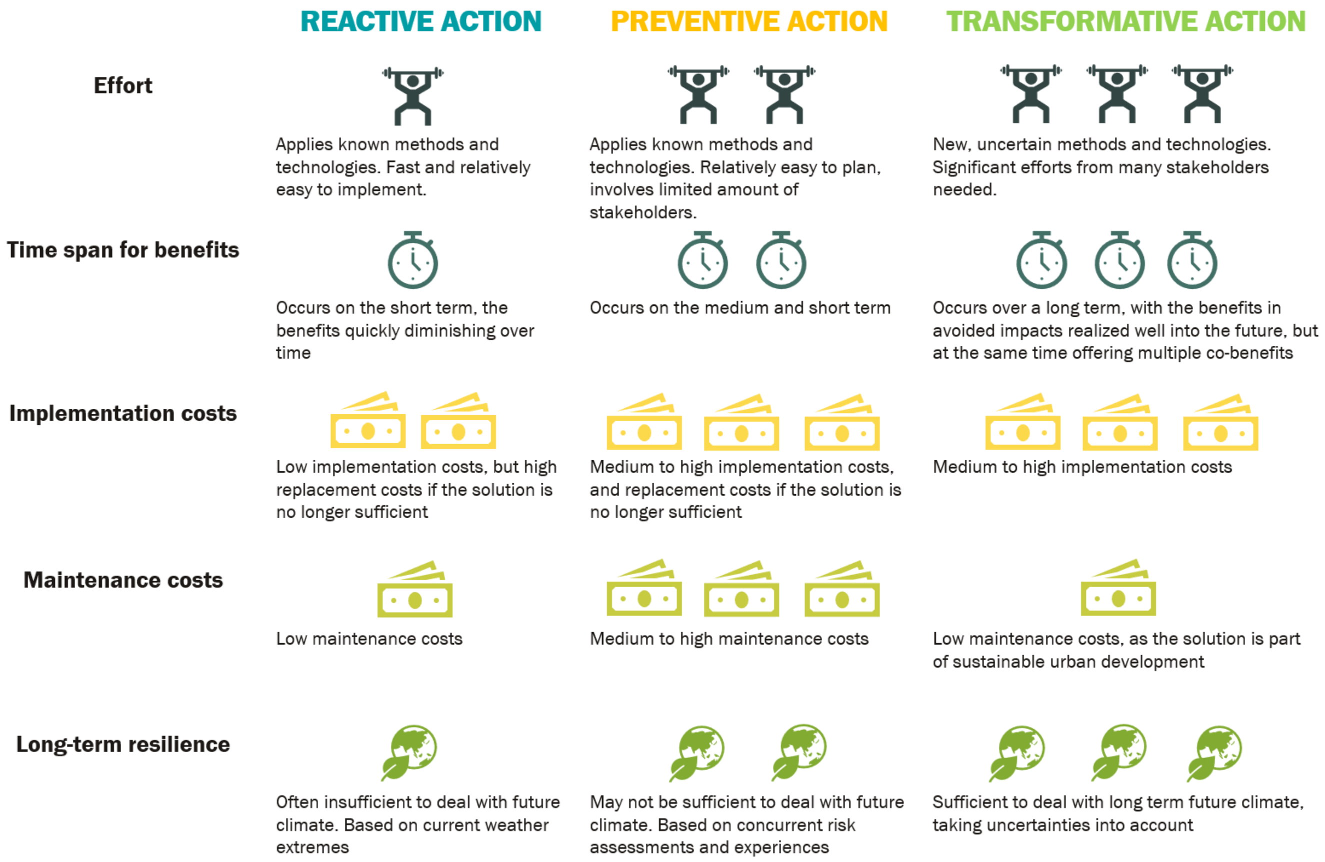


Figure 37: Examples of reactive, preventive, and transformative adaptation strategies, adopted from C40 Cities / CAS, 2020.

This framework is useful for understanding and identifying options to manage climate risks. It has been adopted by the global city network of *C40 Cities* as part of their Climate Action Planning Process. **Reactive** (or coping) and **preventive** (or incremental) approaches to adaptation are most often reported about, whereas **transformative** adaptation is a relatively new concept. Reactive adaptation focuses on the immediate impacts from extreme weather, without changing a city's systems. Preventive adaptation drives adjustments to the existing city systems, building their resilience, while minimizing negative climate change impacts. Transformative adaptation aims to reduce the root causes of climate risks, by transforming the city's systems into more just, sustainable, or resilient states. Figure 38 shows some of the key characteristics for each strategy.



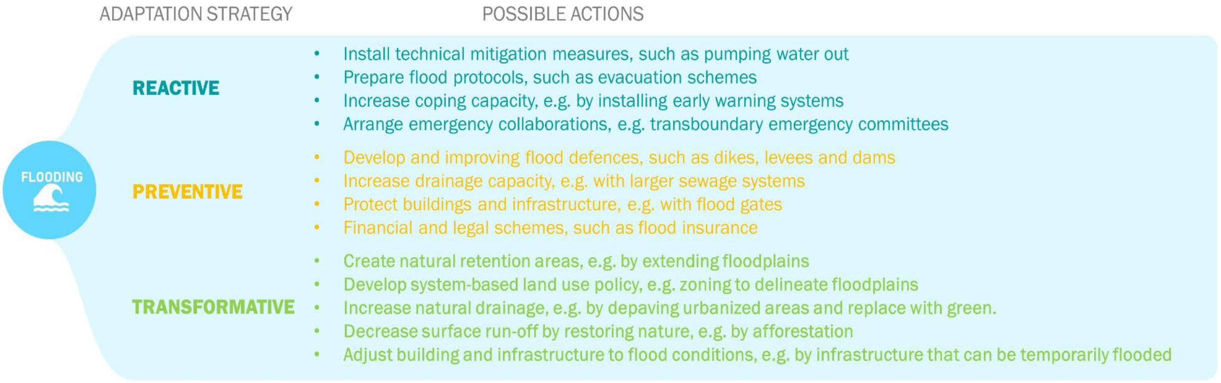
	REACTIVE ACTION	PREVENTIVE ACTION	TRANSFORMATIVE ACTION
Effort	Applies known methods and technologies. Fast and relatively easy to implement.	Applies known methods and technologies. Relatively easy to plan, involves limited amount of stakeholders.	New, uncertain methods and technologies. Significant efforts from many stakeholders needed.
Time span for benefits	Occurs on the short term, the benefits quickly diminishing over time	Occurs on the medium and short term	Occurs over a long term, with the benefits in avoided impacts realized well into the future, but at the same time offering multiple co-benefits
Implementation costs	Low implementation costs, but high replacement costs if the solution is no longer sufficient	Medium to high implementation costs, and replacement costs if the solution is no longer sufficient	Medium to high implementation costs
Maintenance costs	Low maintenance costs	Medium to high maintenance costs	Low maintenance costs, as the solution is part of sustainable urban development
Long-term resilience	Often insufficient to deal with future climate. Based on current weather extremes	May not be sufficient to deal with future climate. Based on concurrent risk assessments and experiences	Sufficient to deal with long term future climate, taking uncertainties into account

Figure 38: Characteristics of the three different adaptation strategies.

Based on these three types, a mix of adaptation actions can be identified. Figure 39 provides some examples for flooding. Related to the identified key risks for CPA, early warning and drainage capacity are examples that came up during the workshop. Early warning (and early action) of storms and tropical cyclones helps to prevent damage to assets, infrastructure, and vessels, and may prevent injury and loss of life. The importance of enough drainage capacity from Zeelandia and Salina towards het Schottegat was highlighted to prevent flooding of the vital road for emergency services. Here, maintenance of the drainage systems was underscored as critical aspect.

There are several online resources that offer an overview of hazard-specific adaptation actions.

- https://resin-cities.eu/resources/library/. A searchable database addressing climate risks including heat, floods and drought.
- https://climate-adapt.eea.europa.eu/en/knowledge/tools/adaptation-support-tool/step-3-1. An online tool that facilitates an exploration of potential adaptation options and helps identify relevant actions, and their potential co-benefits.
- https://www.portofrotterdam.com/nl/waterveiligheid-overzicht. Overview of the most cost-effective water safety measures as identified by the Port of Rotterdam.



ADAPTATION STRATEGY	POSSIBLE ACTIONS
REACTIVE	• Install technical mitigation measures, such as pumping water out • Prepare flood protocols, such as evacuation schemes • Increase coping capacity, e.g. by installing early warning systems • Arrange emergency collaborations, e.g. transboundary emergency committees
PREVENTIVE	• Develop and improving flood defences, such as dikes, levees and dams • Increase drainage capacity, e.g. with larger sewage systems • Protect buildings and infrastructure, e.g. with flood gates • Financial and legal schemes, such as flood insurance
TRANSFORMATIVE	• Create natural retention areas, e.g. by extending floodplains • Develop system-based land use policy, e.g. zoning to delineate floodplains • Increase natural drainage, e.g. by depaving urbanized areas and replace with green. • Decrease surface run-off by restoring nature, e.g. by afforestation • Adjust building and infrastructure to flood conditions, e.g. by infrastructure that can be temporarily flooded

Figure 39: Examples of possible adaptation actions for flooding, for the three different adaptation strategies.

References

le Bars, D. (2022) *Past and future sea level around the BES islands*. De Bilt. Available at: https://cdn.knmi.nl/knmi/pdf/bibliotheek/knmipubTR/TR397.pdf (Accessed: 16 September 2022).

Bloemendaal, N. *et al.* (2022) 'A globally consistent local-scale assessment of future tropical cyclone risk', *Science Advances*, 8(17), p. 8438. Available at: https://doi.org/10.1126/SCIADV.ABM8438/SUPPL_FILE/SCIADV.ABM8438_SM.PDF.

Boon, E. *et al.* (2021) 'Does Transformational Adaptation Require a Transformation of Climate Services?', *Frontiers in Climate*, 3, p. 2. Available at: https://doi.org/10.3389/FCLIM.2021.615291/BIBTEX.

Burkett, V. et al. (2014), Point of departure. In: Field C. et al. (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK/New York, pp 169–194

The European Climate Adaptation Platform Climate-ADAPT (2022), Adaptation options. Available at https://climate-adapt.eea.europa.eu/en/knowledge/adaptation-information/adaptation-measures (Accessed: 7 December 2022).

Climate Studies Group Mona (Eds.) (2020) *The State of the Caribbean Climate | Caribbean Development Bank*. Available at: https://www.caribank.org/publications-and-resources/resource-library/publications/state-caribbean-climate (Accessed: 21 September 2022).

Dale, M. (2021) 'Managing the effects of extreme sub-daily rainfall and flash floodsa practitioner's perspective', *Philosophical Transactions of the Royal Society A*, 379(2195). Available at: https://doi.org/10.1098/RSTA.2019.0550.

Van Duin, M. and Sikkens, E. (2017) *Risicoprofiel Curaçao 2017-2022*.

Fowler, H.J., Wasko, C. and Prein, A.F. (2021) 'Intensification of short-duration rainfall extremes and implications for flood risk: current state of the art and future directions', *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences*, 379(2195), p. 20190541. Available at: https://doi.org/10.1098/rsta.2019.0541.

P.J. Girigori (2011) Impact of climate change on small islands; Curaçao a case study on climate change in climate variability. Unpublished.

Haasnoot, M. *et al.* (2020) 'Adaptation to uncertain sea-level rise; how uncertainty in Antarctic mass-loss impacts the coastal adaptation strategy of the Netherlands', *Environmental Research Letters*, 15(3), p. 034007. Available at: https://doi.org/10.1088/1748-9326/AB666C.

Imhoff, R.O. (2022) ‘Rainfall nowcasting for flood early warning’. Available at: https://doi.org/10.18174/573867.

Knutson, T. *et al.* (2020) ‘Tropical Cyclones and Climate Change Assessment: Part II: Projected Response to Anthropogenic Warming’, *Bulletin of the American Meteorological Society*, 101(3), pp. E303–E322. Available at: https://doi.org/10.1175/BAMS-D-18-0194.1.

Moss, R.H. *et al.* (2010) ‘The next generation of scenarios for climate change research and assessment’, *Nature 2010 463:7282*, 463(7282), pp. 747–756. Available at: https://doi.org/10.1038/nature08823.

Nijsen, R. (1999) ‘Golfdoordringing op de kust van Bonaire tijdens een hurricane’. Available at: https://repository.tudelft.nl/islandora/object/uuid%3A5895ea66-8aa6-4898-940b-2797563a20bf (Accessed: 5 October 2022).

de Palm, J. (1985) *Encyclopedie van de Nederlandse Antillen*. Zutphen: Walburg pers. Available at: https://www.deslegte.com/encyclopedie-van-de-nederlandse-antillen-1381239/ (Accessed: 14 October 2022).

Roberts, M.J. *et al.* (2020) ‘Projected Future Changes in Tropical Cyclones Using the CMIP6 HighResMIP Multimodel Ensemble’, *Geophysical Research Letters*, 47(14), p. e2020GL088662. Available at: https://doi.org/10.1029/2020GL088662.

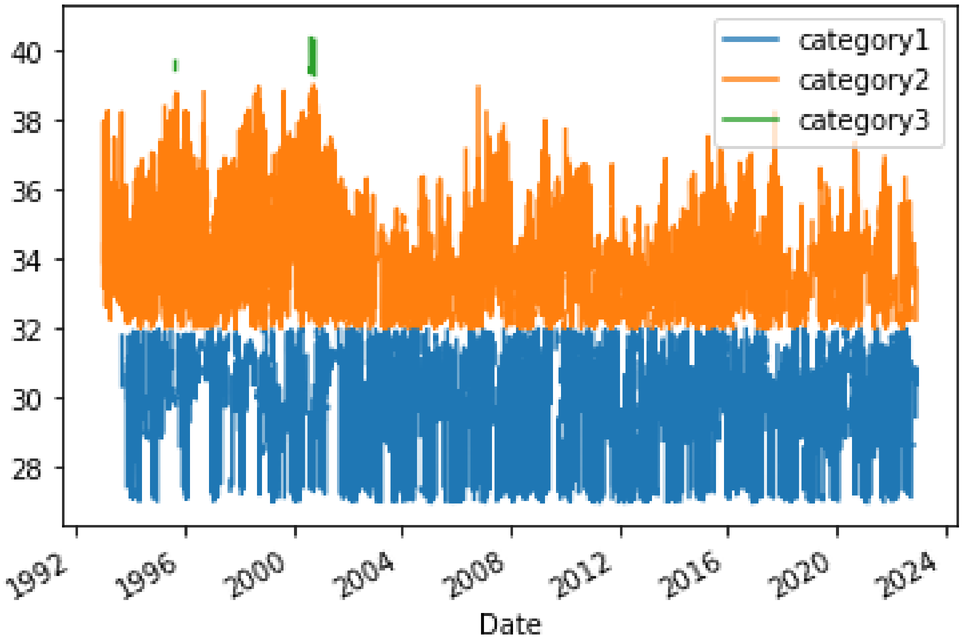
Van Vuuren, D.P. *et al.* (2011) ‘The representative concentration pathways: An overview’, *Climatic Change*, 109(1), pp. 5–31. Available at: https://doi.org/10.1007/S10584-011-0148-Z/TABLES/4.

Werkgroep risico & risicogebieden (1998) ‘Rapport risico-analyse tropische cyclonen Curaçao’.

Annex A– Extended hazard assessment

Heat

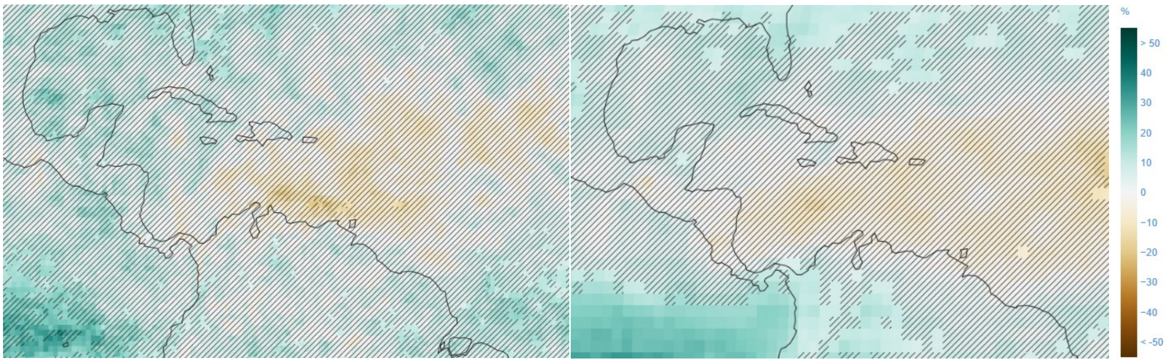
For the assessment of thermal comfort, we calculate the Heat Index for historical observations. The heat index is being used in the weather forecasts of the Meteorologische Dienst Curaçao (MDC). It combines humidity with temperature to calculate the thermal (dis)comfort. Values of the heat index above 27 C° are associated with discomfort. For Curaçao, 95% of the days in 1993-2022 are above this threshold. We do not see an increase in the heat index. The data suggests a slight decrease in the number of days in category 2, which become less hot (category 1). This decrease is related do a decline in the humidity. In this heat index, wind and sunshine (radiation) is not taken into account, which are also important factors for thermal comfort.



Annex 1: Daily heat index for measurements at Hato. For each day, the heat index (in degrees) is categorized. The higher the category, the worse the heat.

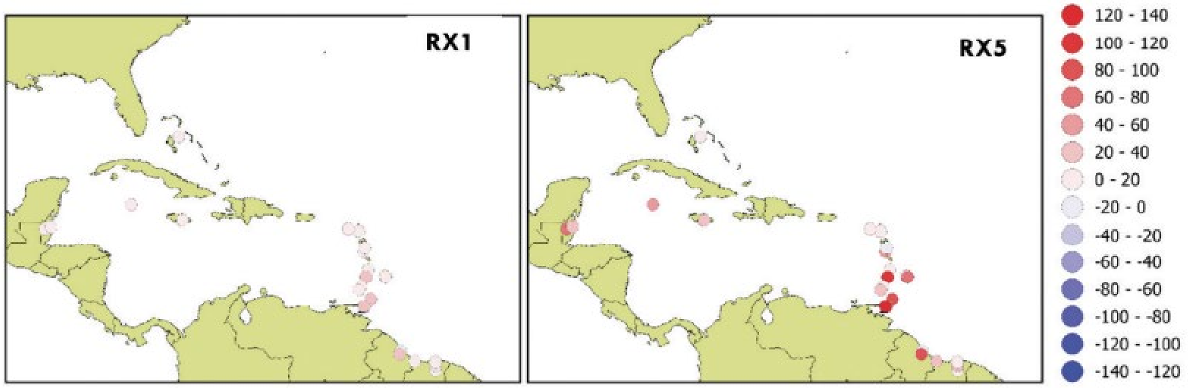
Heavy rainfall

Future projections for Curaçao show that models do not agree on the sign of change of daily rainfall extremes (RX1day), but that on average a decline in heavy rainfall is projected (Annex 2). These results are similar for the latest CMIP6 global models and CMIP5 regional climate models (CORDEX Central America). A similar picture is found for 5-day rainfall extremes. However, it must be noted that these models cannot ‘resolve’ or simulate small scale processes, such as convection, that are relevant for Curaçao. Furthermore, it is under discussion whether ENSO is correctly simulated in these projections (Personal communication Marta and Rein, see Annex C), which means the projections may be too dry (see section 3.2). Thus, these projections for heavy rainfall should not simply be taken for granted and cannot be used to infer trends in hourly heavy rainfall events from cloudbursts. In fact, cloudbursts seem to have increased historically (van Duin and Sikkens, 2017).



Annex 2: RX1day in CORDEX Central America (left) and CMIP6 (right) for 2050 under RCP8.5. Striping shows that models do not agree on the projected signal. Source: Climate Change 2021: The Physical Science Basis. Working Group I Contribution to the IPCC Sixth Assessment Report.

For small Caribbean Islands, trends in heavy rainfall can more reliably be estimated using a statistical downscaling approach (Climate Studies Group Mona (Eds.), 2020). In general, an increase in extreme rainfall is projected for Caribbean Islands (Annex 3, Climate Studies Group Mona (Eds.), (2020). From a physical understanding an increase in rainfall is expected in a warmer climate where warm air can hold more moisture. From these sources of information, we judge that the intensity of heavy rainfall will increase in the future, but we cannot say by how much. KNMI is producing climate scenarios for Bonaire, which may provide additional information on the future change in heavy rainfall. These scenarios are expected to be available in 2023.



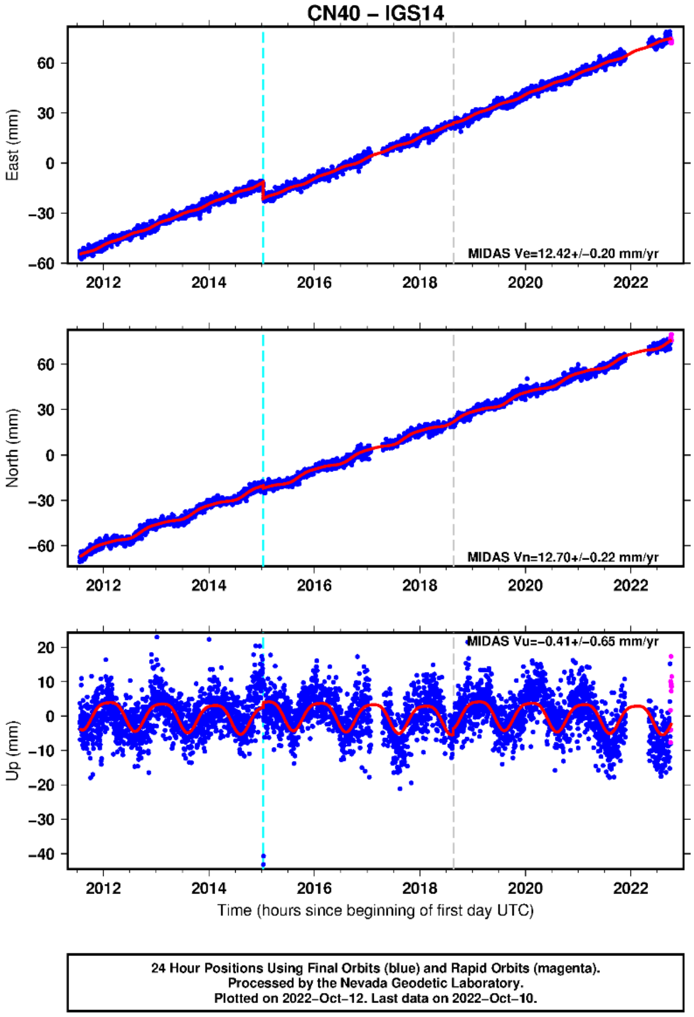
Annex 3: Future projection of extreme 1-day (left) and 5-day (right) rainfall for the period 2090 to 2100 relative to 2006 to 2016 period for RCP 8.5. Units are in mm. Source: Climate Studies Group Mona (Eds.), (2020).

Sea-level rise

Plate tectonic movement of Curaçao

In the discussion of the global sea level increase it is important to take the "local "movement of the Island into account.

On Curaçao the meteorological department operates a GPS station at Hato. Data from this station is processed to illustrate horizontal and vertical movements by Nevada Geodetic Laboratory and the results are presented on their website (http://geodesy.unr.edu/NGLStationPages/stations/CN40.sta). The movements of Curaçao are presented relative to an earth fixed frame, it is also possible to present the movement of Curaçao relative to Caribbean tectonic plate. The movements of Curaçao are presented in Annex 4. Curaçao moves north-east (top and middle panels) but vertical movement is limited with no clear long-term trend (bottom panel). The vertical movement fluctuates during a year, with a yearly "high" around December-January. The horizontal movement is in line with movement of the Caribbean plate.

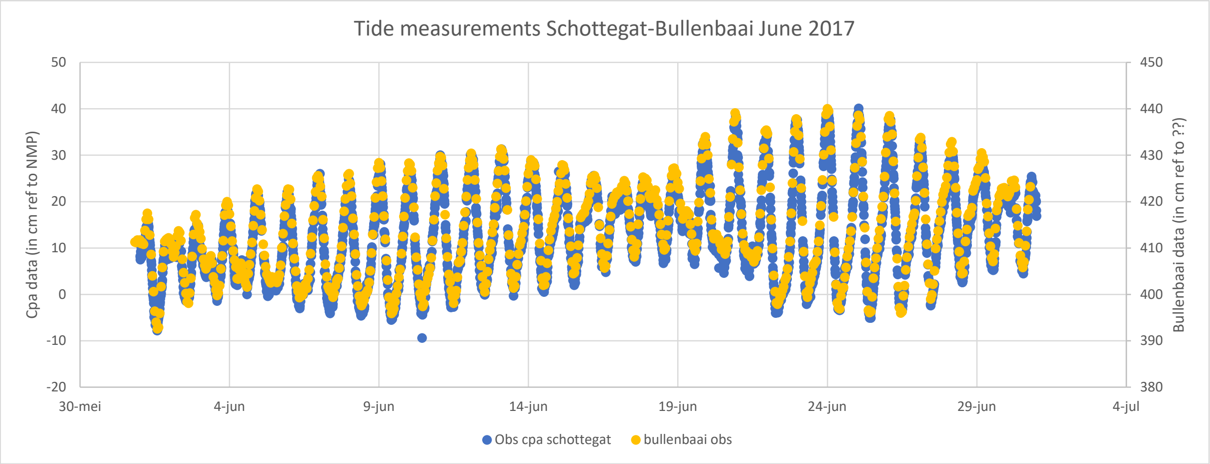


Annex 4: GNSS station at Hato airport, movements in period 2012-2022. Source: (by Nevada Geodetic Laboratory)

As part of the UNESCO Sea level Station monitoring, the meteorological department operates a tide gauge at Bullenbaai. This gauge is in operation as from October 2013 and provides data until May 2022. The vertical reference of this tide gauge is unknown and its relationship with the NMP level of Curaçao is also unknown. Data from this station is available on the web https://uhslc.soest.hawaii.edu/data/?fd . Bullenbaai is station 878. Data is available from October 17th 2013 until May 10th of 2022.

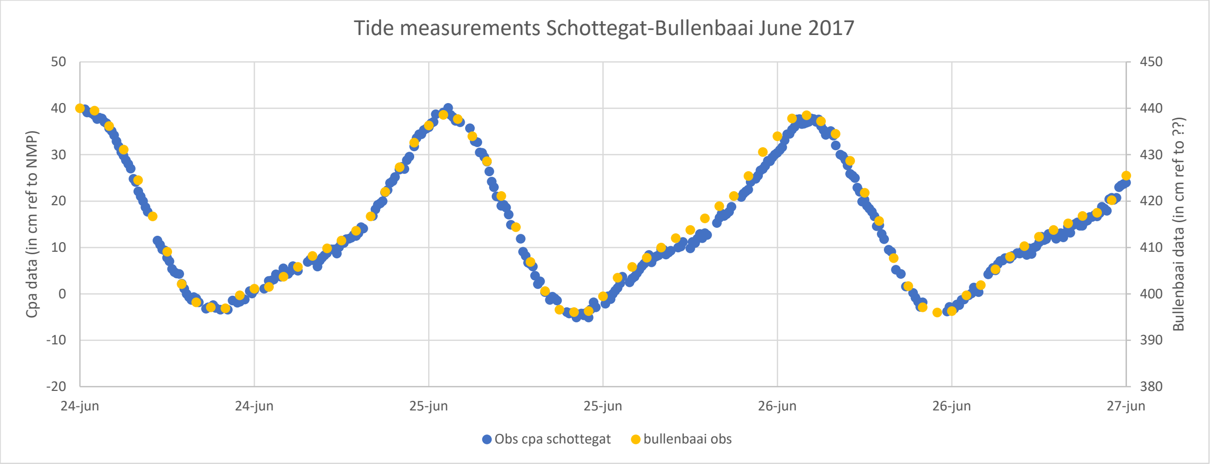
The Curaçao Port Authority re-established a tide gauge in the Schottegat close to its main office. The reference of this tide gauge is NMP (Nieuw Middenstands Peil). The CPA tidal data is available as from May20th 2017 until September 14th 2022. This data contains gaps and missing data. In the earlier days (1960-1995) analogue water level measurements have been executed as well, but an analysis on this data has not been found.

The tidal situations at Bullenbaai and in the Schottegat are very comparable. The measurements of June 2017 of both stations are presented in Annex 5-6.



Annex 5: Tidal measurements at Bullenbaai and Schottegat

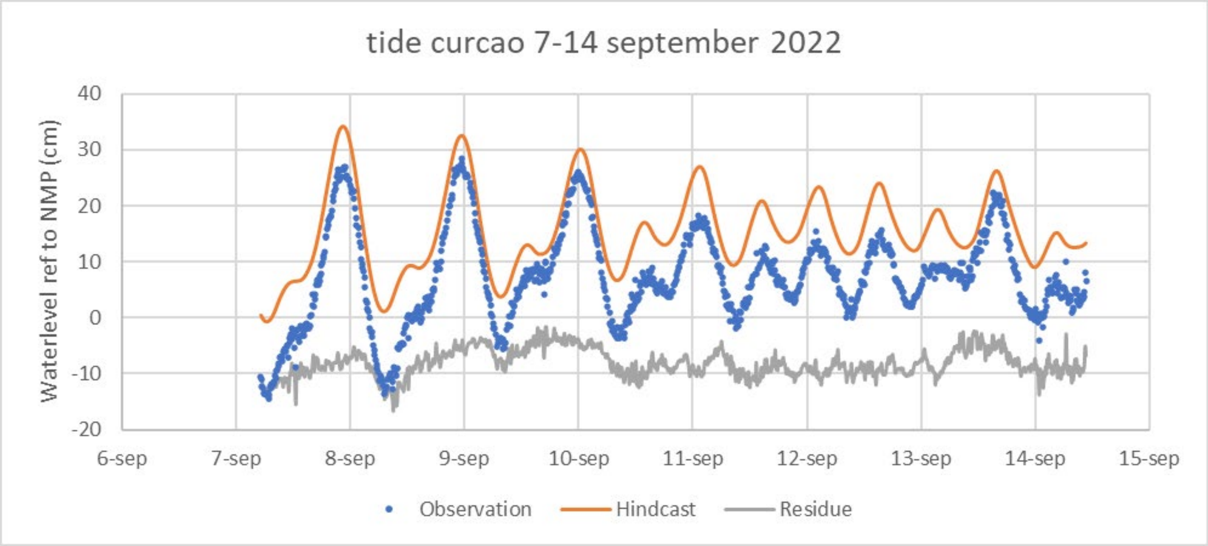
If we further zoom in on the spring tide of June 24th-27th we see that both the timing and measured tide is identical but that the reference levels are different.



Annex 6: Tidal measurements at Bullenbaai and Schottegat

The data as measured at Bullenbaai and Schottegat have been processed using a harmonic analysis (for an explanation see: https://tidesandcurrents.noaa.gov/about_harmonic_constituents.html).
The analysis deduces the tidal influence on the measured data. The difference between the measured water level and the calculated tide defines the non-tidal effects, such as cause by pressure anomalies.

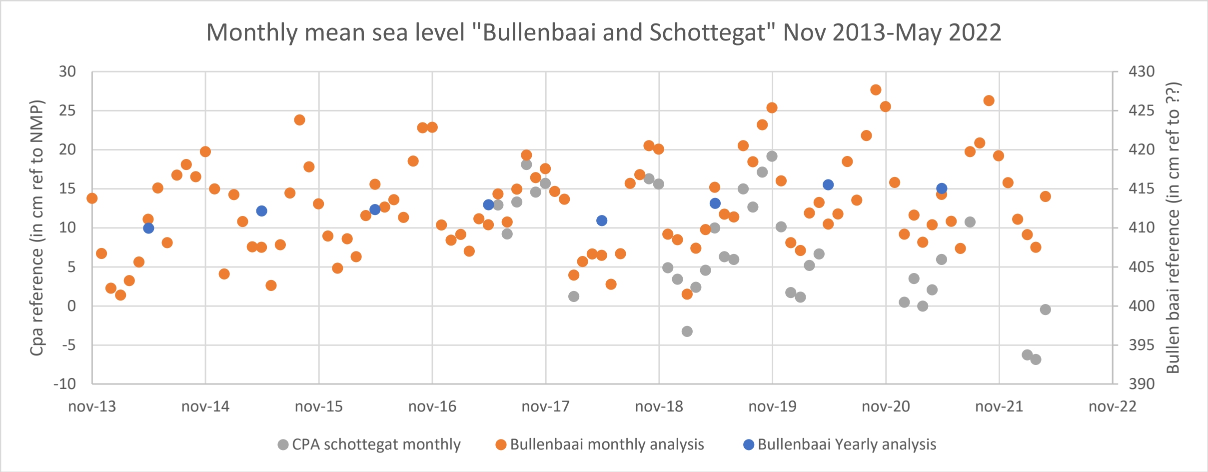
The data of CPA and Bullenbaai have been analyzed on a monthly basis and on the full time series. This results in monthly mean sea level values and tidal constants. An example of this analysis for 7-14 September 2022 is shown in Annex 7.



Annex 7: An example of the harmonic analysis applied to CPA water level measurements for a week in September 2022. It shows the simulated tide levels (orange), the measurements (blue), and the difference between the two, which is a measure of the non-tidal effects (grey).

To reveal developments or trends in mean sea level the data from Bullenbaai and Schottegat have been processed using a harmonic analysis, in this way monthly and yearly sea levels have been obtained. This analysis is presented in Annex 8. From this analysis it becomes clear that monthly trends at Schottegat and Bullenbaai are similar and showing that the August-November water levels are approximately 15-20 cm higher than the March-April levels. The long-term trend of both stations is not similar, this will be related to stability of the local level benchmark. It is advised that for both stations this benchmark is regularly measured (checked) and tied into the Curaçao NMP level.

The tidal analysis also shows that the maximum non-tidal impact on water levels (e.g., surge) in the period November 2013- May 2022 was around 20 cm (the standard deviation of this non tidal effect was 5 cm).



Annex 8: Monthly mean sea level data obtained from CPA (Schottegat) and Meteo Curaçao (Bullenbaai)

The future projections of sea level rise depend on three major unknowns (le Bars, 2022):

- The amount of greenhouse gases that will be emitted
- The speed at which the ice sheets will adapt to the warmer climate
- The reorganization of ocean currents.

With respect to the first, we can explore the uncertainty for different IPCC scenarios (section 2.2). The scenarios result in a spread that increases rapidly over time, ranging from 24-28 cm in 2050 to 47-86 cm in 2100 for scenarios SSP1-1.9 to SSP5-8.5 (see also figure 15 in main text). Furthermore, within each scenario there is uncertainty related to the response of the earth system to the warmer climate (points two and three above). For example, for SSP5-8.5, the range is 20-38 cm in 2050 to 64-117 cm by 2100 – which is larger than the uncertainty from our emissions.

Annex B- Data sources

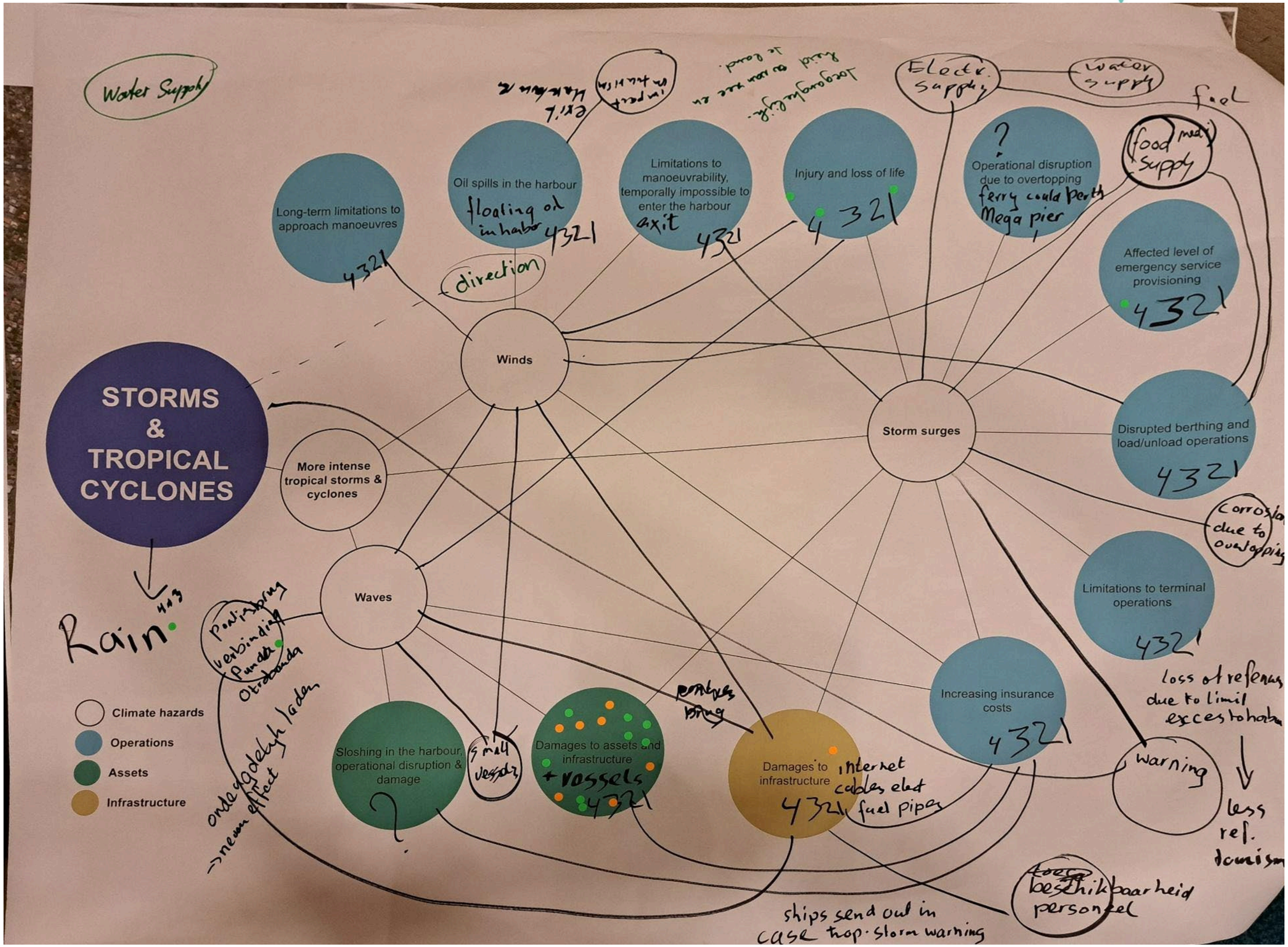
Name	Description	Source (URL)
Climate Summary Curaçao	Summary of observed meteorological variable for the period 1981-2010	https://www.meteo.cw/Data_www/Climate/documents/CLIM_SUM_Cur.pdf
IPCC WGI atlas	An interactive tool that contains information from the IPCC AR6 report	https://interactive-atlas.ipcc.ch/
SMHI data portal	An interactive tool where projections can be assessed for the grid points over Curaçao. It contains the CMIP5 (not the latest CMIP6) models, and regional CORDEX models	https://climateinformation.org
IPCC AR6 Sea-Level Projection Tool	An interactive tool where sea-level projections can be assessed for grid points surrounding Curaçao. It contains the latest IPCC AR6 projections.	https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool
Storm effects atlas	Note: not used directly. Only found through UNOPS source.	CDMP: Atlas of Probable Storm Effects in the Caribbean Sea (oas.org)

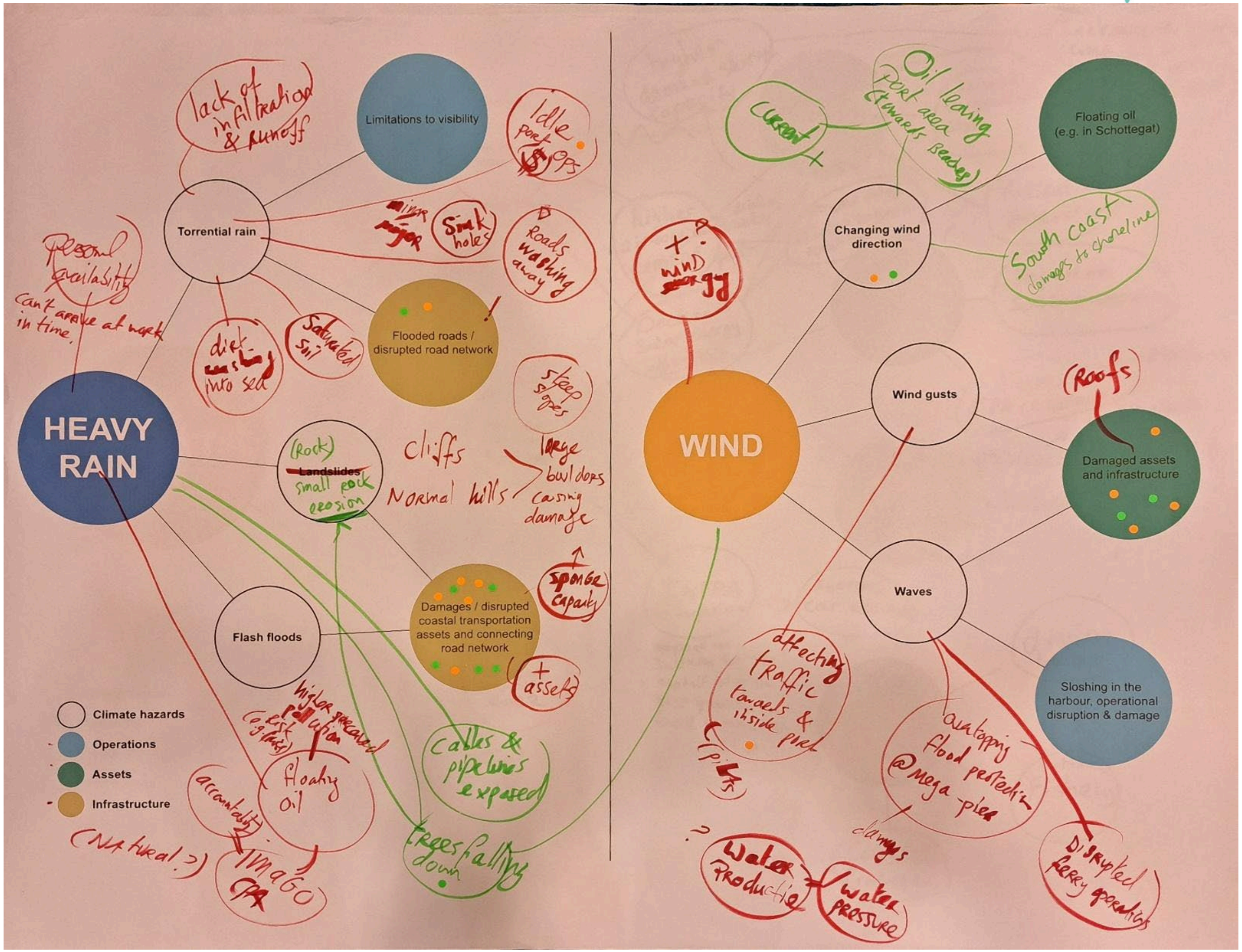
Annex C- Interviews

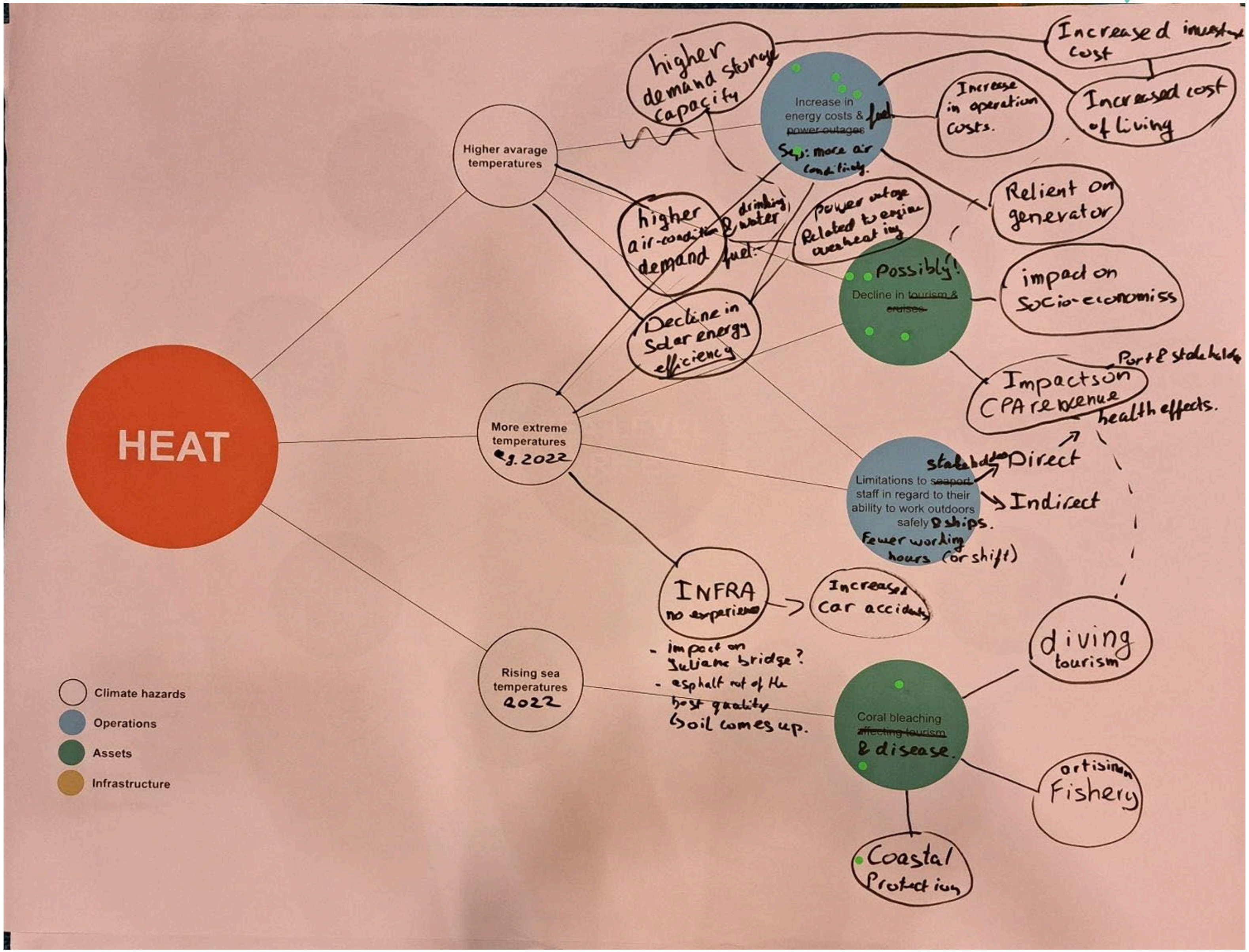
During this project, we conducted the following interviews:

Date	Organization	Consulted experts
13-09-2022	Koninklijk Nederlands Meteorologisch Instituut (KNMI)	Rein Haarsma, Marta Brotons Blanes
13-09-2022	Meteorological Department Curaçao (MDC)	Pedzi Girigori, Frans Werlemann
16-09-2022	IVM-VU	Nadia Bloemendaal
27-09-2022	Koninklijk Nederlands Meteorologisch Instituut (KNMI)	Peter Siegmund

Annex D– Workshop results – impact chains


STORMS & TROPICAL CYCLONES
More intense tropical storms & cyclones
Winds
Waves
Storm surges
Long-term limitations to approach manoeuvres
4321
Oil spills in the harbour
floating oil in harbor
4321
direction
exit harbour &
impact in harbour
Limitations to manoeuvrability, temporally impossible to enter the harbour
axit
4321
Injury and loss of life
4 321
Electr. supply
water supply
fuel
food medi supply
Operational disruption due to overtopping
?
ferry could berth Mega pier
Affected level of emergency service provisioning
4321
Disrupted berthing and load/unload operations
4321
Corrosion due to overtopping
Limitations to terminal operations
4321
loss of refenues due to limit excess to harbour
less ref. tourism
Increasing insurance costs
4321
warning
beschikbaarheid personeel
ships send out in case trop. storm warning
Damages to infrastructure
4321
internet cables elect fuel pipes
Damages to assets and infrastructure
+ vessels
4321
small vessels
Sloshing in the harbour, operational disruption & damage
?
Rain
4 1 3
Water Supply
pontjesbrug verbinding Punda Otrobanda
ondergedeelte laden
→ neven effect
Climate hazards
Operations
Assets
Infrastructure


HEAVY RAIN
Torrential rain
Limitations to visibility
Flooded roads / disrupted road network
~~Landslides~~
Flash floods
Damages / disrupted coastal transportation assets and connecting road network
lack of infiltration & runoff
Idle port ops
minor major
Sink holes
Roads washing away
Personal availability
Can't arrive at work in time.
dirt washing into sea
Saturated soil
!
steep slopes
(Rock)
small rock erosion
cliffs
Normal hills
large bulders causing damage
Sponge capacity
+ assets
higher speculated pollution risk (e.g. tanks)
floating oil
accountability
(Natural?)
Imago
cables & pipelines exposed
trees falling down
Climate hazards
Operations
Assets
Infrastructure
WIND
Changing wind direction
Floating oil (e.g. in Schottegat)
Wind gusts
Damaged assets and infrastructure
Waves
Sloshing in the harbour, operational disruption & damage
Current +
Oil leaving port area (towards beaches)
South coast damages to shoreline
+? wind energy
(Roofs)
affecting traffic towards & inside pier
(pilots)
overtopping flood protection @mega-pier
damages
Disrupted ferry operations
?
Water production
Water pressure


HEAT
Higher avarage temperatures
More extreme temperatures e.g. 2022
Rising sea temperatures 2022
higher demand storage capacity
Increase in energy costs & ~~power outages~~ fuel
Sep: more air conditioning.
Increased investment cost
Increase in operation costs.
Increased cost of Living
higher air-condition demand
drinking water
fuel.
power outage Related to engine overheating
Relient on generator
Possibly!
Decline in ~~tourism & cruises~~
impact on Socio-economiss
Decline in Solar energy efficiency
Impacts on CPA revenue
Port & stakeholders
health effects.
Limitations to ~~seaport~~ stakeholders staff in regard to their ability to work outdoors safely & ships.
Fewer working hours (or shift)
Direct
Indirect
INFRA
no experience
Increased car accidents
- impact on Juliana bridge?
- asphalt not of the best quality
Soil comes up.
diving tourism
Coral bleaching ~~affecting tourism~~ & disease.
artisinal Fishery
Coastal Protection
Climate hazards
Operations
Assets
Infrastructure

Annex E– List of sector-based impacts

Climate themes	Sectors
Heat	Operations - Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Heavy rain	Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
Storms & tropical cyclones	Infrastructure - port infrastructure, e.g. channels, sea locks, rail and road connections, tunnels and bridges
Sea-level rise	
Wind	

Climate theme	Hazard	Impact	Impact description	Source	Sector
Select the overarching climate theme	*Write down the relevant hazards of your city, categorized per relevant climate theme*	*Write down the relevant impacts*	*Write down how the hazard affects the sector (e.g. Infrastructure less available due to floods, yield loss due to drought, more diseases due to heat, etc)*	*Source of the impact description*	*Select the relevant sector for this impact*
Heat	More extreme temperatures	Increase in investment costs for higher fuel storage capacity	With more demand for fuel during heat extremes, the storage capacity to cover this should be higher.	Monioudi, 2018	Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
Heat	Higher average temperatures, more extreme temperatures, rising sea temperatures	Decline in tourism and cruises impacts CPA stakeholders revenue	With rising sea temperatures corals in the Caribbean are already being impacted, affecting diving tourism. Furthermore, hotter temperatures may make it less appealing for tourists to come to Curacao.	Spencer, 2022	Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
Heat	Rising sea temperatures	Coral bleaching affecting coastal protection			Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
Heat	More extreme temperatures	Increase in car accidents	Asphalt is not of the best quality, which means that oil may surface during extreme temperatures leading to slippery conditions.		Infrastructure - port infrastructure, e.g. channels, sea locks, rail and road connections, tunnels and bridges
Heat	More extreme temperatures	Revision of construction design standards	It is good to stress test construction design to future extremes > 40 degrees. For example, is there an impact on Juliana bridge as rail expands with hot weather?		Infrastructure - port infrastructure, e.g. channels, sea locks, rail and road connections, tunnels and bridges
Heat	Higher average temperatures, more extreme temperatures	Limitations to stakeholders staff in regard to their ability to work outdoors and in ships safely (or shift in working hours)	Both direct impacts due to e.g. unbearable working condi	Izaguirre, 2020	Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Heat	Higher average temperatures, more extreme temperatures	Increase in costs from energy, drinking water, and fuel due to high demand	With hotter temperatures there is more demand for air co	Monioudi, 2018	Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Heat	Higher average temperatures, more extreme temperatures	Increase in power outages related to engine overheating			Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations

Climate themes	**Sectors**
Heat	Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Heavy rain	Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
Storms & tropical cyclones	Infrastructure - port infrastructure, e.g. channels, sea locks, rail and road connections, tunnels and bridges
Sea-level rise	
Wind	

Climate theme	**Hazard**	**Impact**	**Impact description**	**Source**	**Sector**
Select the overarching climate theme	*Write down the relevant hazards of your city, categorized per relevant climate theme*	*Write down the relevant impacts*	*Write down how the hazard affects the sector (e.g. Infrastructure less available due to floods, yield loss due to drought, more diseases due to heat, etc)*	*Source of the impact description*	*Select the relevant sector for this impact*
Heavy rain	Torrential rain	Erosion and washing away of soil causing damages (e.g. trees falling down, exposed pipelines & cables, roads washing away)			Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
Heavy rain	Torrential rain	Flooded roads / disrupted road network			Infrastructure - port infrastructure, e.g. channels, sea locks, rail and road connections, tunnels and bridges
Heavy rain	Torrential rain, flash floods	Damages / disrupted coastal transportation assets and connecting road network		Monioudi, 2018	Infrastructure - port infrastructure, e.g. channels, sea locks, rail and road connections, tunnels and bridges
Heavy rain	Torrential rain	Limitations to visibility		Izaguirre, 2020	Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Heavy rain	Torrential rain	Idle port operations during rainfall event (e.g. staff not arriving at work in time)			Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Heavy rain	Torrential rain	Dirt washing into sea			Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations

Climate themes	Sectors
Heat	Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
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Sea-level rise	Rising sea level	Quays, jetties, and breakwaters may require redesigning and/or strengthening		Monioudi, 2018	Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
Sea-level rise	Rising sea level	Tourism revenue decrease due to loss in sandy beaches	Sandy beaches are threatened by climate-change-induced sea level rise. Loss in sandy beaches, results in hotel room loss and thus tourism revenue decrease. Curacao: ~0.7% loss towards 2015 (RCP45/RCP85), ~29.2% - 32.2% loss towards 2100 (RCP45/RCP85)	Spencer, 2022	Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
Sea-level rise	Rising sea level	New equipment and facility maintenance needs		Becker, 2012	Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
Sea-level rise	Rising sea level	Revision of construction design standards		Becker, 2012	Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
Sea-level rise	Rising sea level	Operational disruption due to siltation or scouring problems	Increasing sea levels could alter nearshore flows inducing port scouring and/or silting	Monioudi, 2018	Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Sea-level rise	Rising sea level	Affected wave height pattern & agitation within the harbor		Sierra, 2014	Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Sea-level rise	Rising sea level	Affected logistics			Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Sea-level rise	Rising sea level	Affected surrounding community and environment		Becker, 2012	Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations

Climate themes	Sectors
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Storms & tropical cyclones	Winds, Storm surges, Waves	Damages to assets, infrastructure and (small) vessels	Waves caused damage in the week of September 2022. Swells from Hurricane Ivan on September 7, 2004, battered several constructions on the ABC coasts. Rough seas during Tropical Storm Joan pounded exposed harbor and beach facilities.	Izaguirre, 2020	Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
Storms & tropical cyclones	Winds, waves and storm surges	Increased corrosion due to overtopping			Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
Storms & tropical cyclones	Winds	Floating oil exits harbor to open sea and impacts beaches and marine life	Existing floating oil at west side of Schottegat moves east to harbor area due to change of wind direction during tropical cyclone. During very unfavorable situations the floating oil will reach open sea and impacts marine life and beaches		Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
Storms & tropical cyclones	Winds, waves and storm surges	Damage to infrastructure including (internet) cables and fuel pipes	Existing floating oil at west side of Schottegat moves east to harbor area due to change of wind direction during tropical cyclone. During very unfavorable situations the floating oil will reach open sea and impacts marine life and beaches		Infrastructure - port infrastructure, e.g. channels, sea locks, rail and road connections, tunnels and bridges
Storms & tropical cyclones	Winds, Storm surges, Waves	Connection between Punda and Otrobanda (Emma bride and ferries) temporary out of order			Infrastructure - port infrastructure, e.g. channels, sea locks, rail and road connections, tunnels and bridges
Storms & tropical cyclones	Winds, Storm surges, Waves	Limitations to maneuverability, temporarily impossible to enter and/or exit the harbor		Izaguirre, 2020	Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Storms & tropical cyclones	Winds, Storm surges, Waves	Disrupted berthing and load/unload operations		Izaguirre, 2020	Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Storms & tropical cyclones	Winds, Storm surges, Waves	Operational disruption due to overtopping. Ferry can't berth. Mega pier flooded	Wave overtopping is the process of water crossing the flood protection over its crest due to wave action. It occurs when the crest levels are not high enough to prevent waves from rushing up against the structure and thereby exceeding the crest level	Izaguirre, 2020	Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations

Climate themes	Sectors
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Heavy rain	Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
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Storms & tropical cyclones	Winds, Storm surges, Waves	Limitations to terminal operations		Izaguirre, 2020	Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Storms & tropical cyclones	Winds, waves and storm surges	Increasing insurance costs			Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Storms & tropical cyclones	Winds, waves and storm surges	Affected level of emergency service provisioning			Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Storms & tropical cyclones	Winds, waves and storm surges	Injury and loss of life	Tropical storm Tomás developed late October 2010 and became a hurricane when it was located near St. Vincent on October 29. It weakened to a minor tropical storm on November 1 and the center passed about 115 kilometers north of the ABC Islands, later that day. A feeder band developed during the early evening of the same day and barely moved throughout that night. The result was a persistent heavy thunderstorm activity over mainly the south-eastern half of Curaçao and parts of Bonaire. In Curaçao, this heavy rain led to a couple of deaths and an estimated flood damage of about US$200 million.	Meteorological Department Curacao, 2018	Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Storms & tropical cyclones	Winds	Floating oil reaches harbor area resulting in claims due to dirty ships	Existing floating oil at west side of Schottegat moves east to harbor area due to change of wind direction during tropical cyclone.		Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Storms & tropical cyclones	Winds, waves and storm surges	Flooding of power plant area, resulting in electricity supply interruption and consequently water supply interruption	The power plants of Aqualectra are located in the Schottegat area on low laying lands and are vulnerable to flooding. Local water production is depending on power supply.		Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Storms & tropical cyclones	Winds, waves and storm surges	Disrupted supply (food, fuel) due to disrupted load/unload operations			Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations

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Heavy rain	Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
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Storms & tropical cyclones	Winds, waves and storm surges	Loss of revenues due to limited access to harbor. Losing image of "safe harbor"			Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Storms & tropical cyclones	Winds, waves and storm surges	Increase of "false" warnings due to increased frequency of tropical cyclones	At each warning preparation for the cyclone (such as taking out of service of Emma bridge and ferries has to be taken. (Ships in harbor are demanded to go to open sea in case of a hurricane).		Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Wind	Changing wind direction	Floating oil (e.g. Schottegat), potentially floating to the coast & open sea (affected public perception of CPA)			Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
Wind	Wind gusts	Damaged assets (roofs) and infrastructure			Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
Wind	Waves	Damaged assets and infrastructure			Assets - port structures & buildings, e.g. offices, tanks & silos, terminals, cranes
Wind	Wind gusts	Affected shipping traffic towards and inside the port area			Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Wind	Waves	Overtopping of flood protection at the mega pier			Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Wind	Waves	Disrupted ferry operations			Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations
Wind	Waves	Sloshing in the harbor, operational disruption & damage			Operations – Ship, cargo, yachting & cruise services, e.g. tugs, bunkers, repair & maintenance, terminal operations

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