Nature-based Solutions for flood resilience on Bonaire

A scoping study

Rens A. de Boer, Roy E. Molenaar, Rutger Dankers, Sverre van Klaveren, Bertram de Rooij, Peter Verweij

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The World Wide Fund for Nature Netherlands (WWF-NL) asked Wageningen Environmental Research (WENR) to carry out a scoping study to assess weather impacts on Bonaire and explore the potential of Nature-based Solutions (NbS) to reduce future environmental impacts from extreme weather events and improve flood resilience. Existing data was collected, literature was reviewed and on-site interviews were conducted on Bonaire with different types of stakeholders. By investigating the system and its hydrological, ecological and socio-economic components we describe a 'pathway to impact' of the up- and downstream processes that increase the risk of flooding. Tackling urban flooding and the impact of heavy rain requires an integral approach with hybrid solutions. NbS implementations can support the ameliorating of flood resilience on Bonaire. Upstream revegetation, the greening of kunukus (rural areas) and water retention can help to improve infiltration and slow down runoff. In addition, revitalization of rooien (waterways) and buffer zones can slow down discharge and reduce flood peaks. More room for green and water creates a safer and healthier living environment in the downstream urban area of Kralendijk.

Keywords: Nature-based Solutions, Climate adaptation, Flood resilience, Bonaire, Dutch Caribbean

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Summary

A period of extreme rainfall in November 2022 disrupted society on Bonaire for days. Streets were flooded in Kralendijk for extended periods, and runoff water mixed with pollutants and sewage threatened coral reefs around the island. This impact fits into a trend noticed on other Caribbean islands. This scoping study was carried out to assess the weather impact and explore the potential of Nature-based Solutions (NbS) to reduce future environmental impacts from extreme weather events and improve flood resilience. Existing data was collected, literature was reviewed and on-site interviews were conducted on Bonaire with different types of stakeholders. Outcomes of the heavy rainfall event assessment, in which a number of weather stations were analysed, showed that precipitation amounts were recorded between 58.9 and 84.1 mm within a few hours in the morning of 8 November. Significant precipitation amounts were also measured in the days prior to the heavy rainfall event. In total, 76 reports of impacts from the heavy rainfall on 8 November have been found. The majority of these were related to flooding: often flooding of roads, although gardens and property were flooded as well. Annual precipitation is expected to decrease in the Caribbean region, and storms are predicted to worsen with climate change. By investigating the system and its hydrological, ecological and socio-economic components we state that upstream there is a lack of (healthy) soil and no absorption capacity that leads to surface runoff. High erosion rates are caused due to the lack of vegetation. Saliñas (salt marshes) and other retention areas are under pressure downstream by built-up areas. A good water infrastructure is lacking and wastewater problems occur in Kralendijk. These up- and downstream processes increase the risk of flooding and bring sediment and sewage plumes into the sea, which negatively affect coral reefs. Tackling urban flooding and the impact of heavy rain on the Marine Park requires an integral approach with hybrid solutions. NbS implementations can support the ameliorating of flood resilience on Bonaire. Upstream revegetation, the greening of kunukus (rural areas) and water retention can help to improve infiltration and to slow down runoff. In addition, revitalization of rooien (channels) and buffer zones can slow down discharge and reduce flood peaks. More room for green and water creates a safer and healthier living environment in the downstream urban area of Kralendijk. We conclude that restoring and revitalizing the natural system on Bonaire has potential. To find the most suitable NbS locations in the upstream part of the catchment, the hydrological system and soil properties should be better studied on-site. This scoping study can be seen as a preparation for a more in-depth analysis of NbS application on Bonaire. We recommend the implementation of a transition design process in which different stakeholders, policy makers and local communities are involved in order to support the implementation of NbS and to achieve the optimum impact of the proposed measures.

1 Introduction

Bonaire – one of the Dutch Caribbean islands – experienced heavy rainfall in November 2022. This event led to flooding in the urban area of Kralendijk and damaged the coral reefs in the Marine Park surrounding the islands. Extreme weather events and their subsequent impacts add to the many challenges the island is already facing: managing tourism and an influx of new inhabitants, high erosion rates, rapid urban expansion, waste water management, and reversing the degradation of terrestrial and marine ecosystems. The outlook of climate change – changing weather patterns and sea level rise – underpins the urgency to start working on climate resilience on Bonaire.

Neglecting the natural environment in the future development of Bonaire will not only exacerbate many of these issues but also misses an opportunity to let nature aid Bonaire in its societal challenges. On the other hand, restoring the natural environment can improve the climate resilience of Bonaire while simultaneously addressing several key issues, like biodiversity loss and flood security. The concept of using nature as a way to enhance resilience is known as 'Nature-based Solution' (NbS). The United Nations Environmental Assembly defined NbS in a resolution in 2022 as 'actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits.' The fundamentals of NbS are derived from established sustainable land and water management practices, disaster reduction and climate resilience measures and cover a wide array of possible measures for a variety of issues. Relevant guidelines are available, such as the 'Natural and Nature-based Flood Management: A Green Guide (World Wildlife Fund, 2016)', that can be implemented in various regions.

This report presents the results of a scoping study into the potential for implementing nature-based climate adaptation measures on Bonaire, with the aim of improving resilience against future heavy rainfall events in the Kralendijk area, the coral reefs in the Bonaire Marine Park and the uphill kunuku (rural areas) landscape. Our study benefits from the previous work of scientists, governments and organisations that have created the knowledge base on the natural and socio-economic system of Bonaire. In particular, it builds on the Nature-Inclusive Vision for Bonaire that was developed through a collaboration of a large diverse group of local stakeholders and scientists (Verweij et al., 2022; Verweij et al., in prep), to set the scene for NbS on the island.

Many stakeholders on the island have kindly helped us by providing valuable insights into the flooding related issues and the possible (nature-based) solutions that could help to address these. We interviewed representatives from local government, NGOs, companies and society at large. This demonstrated the enormous amount of knowledge present on the island and the diversity of viewpoints relating to water management, the natural system and the challenges that Bonaire is facing.

Diminishing urban flooding caused by heavy rain events on Bonaire requires an integral approach to avoid taking measures which only address symptoms when it is actually a systemic issue. In this report we propose a comprehensive strategy across the catchment: from upstream areas, via the urban fabric, down to the coral reefs. Actors in this system, in their respective locations and roles, ideally contribute to the solutions to generate co-benefits. This requires a shared understanding of the socio-ecological system, the impact pathway and the co-dependency of interventions.

2 Heavy rainfall and climate change: assessing the impact of heavy rainfall on Bonaire

2.1 Weather and climate on Bonaire

Bonaire is situated in the so-called Southern Caribbean Dry Zone and is characterized by a semi-arid to arid climate, a distinguishable dry and rainy season, and sustained moderate easterlies (Caribbean Meteorological Department Curaçao, n.d.; Verweij et al., 2020). The dry season runs from February till June, whereas the rainy season starts in September and ends in January. The months of July and August can be considered as transitional months. During the rainy season, rain showers usually occur during the early mornings or early to late evening hours (Meteorological Department Curaçao, n.d.; Schmutz et al., 2017).

The tropical climate on Bonaire exhibits small temperature differences between seasons with seasonal mean temperatures between 26 and 29 degrees Celsius. The total amount of precipitation is 465 mm on average per year, and this region can therefore be considered as relatively dry. There is a relatively rainy period between October and December, with November being the wettest month. However, precipitation remains usually below 100 mm per month (Meteorological Department Curaçao, n.d.). Climatological information based on observations on Bonaire in different time periods are given in Figure 1 and Figure 2.

From June to November, but especially from August to October, Atlantic tropical cyclones pose a significant threat to communities in the Caribbean. True hurricanes are relatively rare at the latitudes of Bonaire compared to the rest of the Caribbean, as Bonaire is situated on the southern fringes of the Atlantic hurricane belt. However, hurricanes passing by at relatively short distances and less-intense tropical storms and depressions, along with the associated hazards of heavy rainfall and large swells, can still cause significant damage on Bonaire.

Meteorological observations are collected at the official Royal Netherlands Meteorological Institute (KNMI) weather station at Flamingo Airport. In addition, a number of private weather stations are run, mostly by weather enthusiasts.

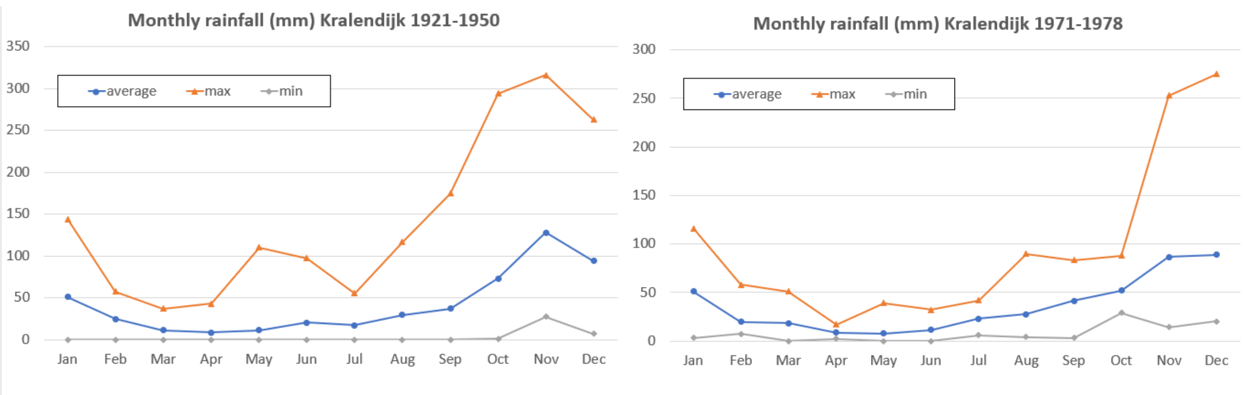

Figure 1 *Average monthly rainfall in mm between 1921-1950 (left) and 1971-1978 (right). Data source: Global Historical Climatology Network daily (Lawrimore et al., 2011).*

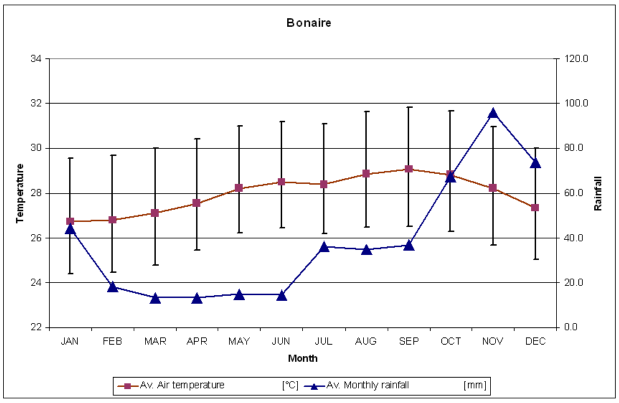

Figure 2 *Climatology Flamingo Airport, Bonaire for the reference period 1971-2000. source: Meteorological Department Curacao.*

2.2 Rainfall event November 2022

A period of extreme rainfall in November 2022 disrupted society on Bonaire for days, with a peak in the night from Monday 7 to Tuesday 8 November. Streets were flooded for extended periods and runoff water mixed with pollutants and sewage threatened coral reefs around the island. Figure 3 shows the measured precipitation at different weather stations. The official meteorological station of Bonaire is located at Flamingo Airport. This station recorded around 59 mm of precipitation on 8 November 2022. The other stations, represented with circles on the map, are personal weather stations that are openly available (Weather Underground, www.wunderground.com). The highest amount measured was 84.1 mm, and other stations reported cumulative precipitation values ranging from 66.5 mm to 82 mm.

The selected personal weather stations (PWS) give a good indication of the precipitation in Kralendijk, since it seems that the station at the airport was located outside the highest intensity of the event and probably underestimated the total precipitated amount. There are more personal weather stations available on Bonaire, but they did not record the rainfall peak well because of power outages in Kralendijk during the heavy rainfall event.

Figure 3 *Measured precipitation for official and unofficial weather stations on 8 November 2022. Background: OpenStreetMap.*

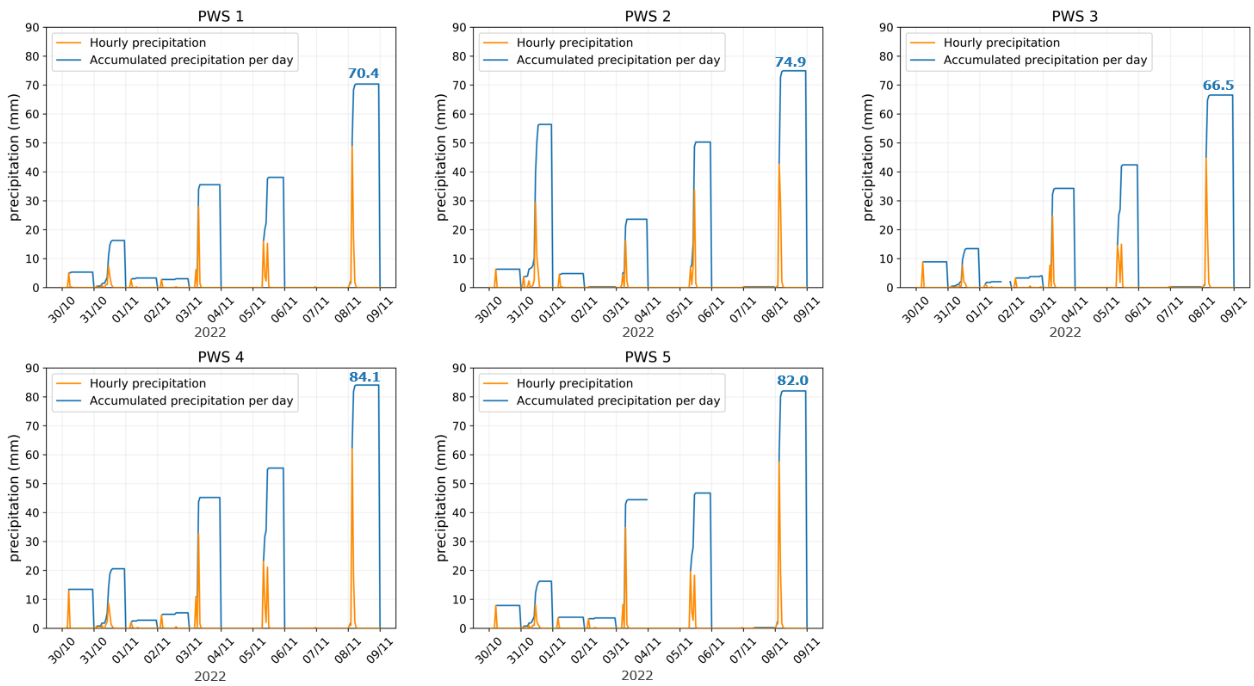

Figure 4 *Accumulated and hourly precipitation for personal weather stations (PWS) on Bonaire for the period 30.10.2022-9.11.2022. Data retrieved from Weather Underground.*

Figure 4 shows the recorded precipitation of the PWS in and around Kralendijk. The locations of the PWS are also indicated in Figure 3. The timeseries present the accumulated precipitation values and hourly precipitation between 30.10.2022 and 9.11.2022. The highest amounts were recorded on 8 November, when rainfall rates of more than 50 mm per hour were recorded. However, some significant precipitation amounts were also measured the days prior to the heavy rainfall event. It is likely that these antecedent wet conditions have contributed to the increased risk of flooding.

According to the meteorological data recorded at Flamingo Airport, a total amount of around 300 mm was measured in November 2022. Compared to the climatology, this is more than three times as much than the 100 mm that falls on average in November.

2.3 Impact assessment

The heavy rainfall on 8 November led to severe disruptions on the island. Data on the impacts of severe weather events like this are not routinely collected, but it is possible to source information on the impacts from non-traditional sources, such as news reports and social media (Spruce et al., 2021; Wyatt et al., 2023). To obtain more insight into the consequences of heavy rainfall, we collected impact data from a number of online news outlets as well as social media (primarily Facebook and Twitter). The focus here was on the rainfall event of 8 November, but we note here that impacts had already occurred earlier in the season. For example, reports of flooding and road closures were also found for the 31 October and 3 and 5 November 2022.

The heavy rainfall in the night of 7 to 8 November, peaking in the morning of 8 November, led to widespread reports of flooding and associated disruption. This included photos and videos shared online. In many cases the location was not mentioned but could be identified from the photo and/or video with the help from local people, although some reports could not be geolocated.

An overview of the impact reports is given in Figure 5 and Table 1. In total, 76 reports of impacts from the heavy rainfall on 8 November could be found. The majority of these related to flooding: often flooding of roads, although gardens and property were flooded as well. Other categories include power cuts to multiple neighbourhoods and disruption of other services, notably health services. There were also reports of damage to nature, specifically sediment runoff into the sea (which can have a long-term impact on corals and dependent sectors such as fisheries and tourism) and damage to some of the mangroves on the Eastern side of the island. In total 46 different impact locations could be identified (see Figure 5). Some of the remaining impact reports could not be located, or include more general impact descriptions that do not apply to a single location, such as schools across the island being closed.

Several prominent impacts that were reported are highlighted in Figure 5. They include the hospital being closed (except for emergencies) for two consecutive days, schools being closed on the 8th, and power cuts in several areas. A dam was overtopped or burst in the area of Amboina, causing widespread flooding. Due to damage from the flooding several tourist attractions, such as a golf course, donkey sanctuary and the Washington Slagbaai National Park on the Northern side of the island, were closed for several days (the National Park for several weeks). To deal with the aftermath and to avoid damage from debris, people were asked to stay at home as much as possible on the day of the event, further disrupting society and the economy. However, no reports of the financial costs could be found, and an estimate of the total economic damage has therefore not been made.

Table 1 *Overview of impact types reported in news and social media following the heavy rainfall on 8 November 2022.*

Impact category	Number of reports
Flooding of roads, yards, property	47
Disruption of services, including health services	10
Disruption of electricity, water supply	8
Impacts on nature	6
Damage to road, property or facilities	5

As is often the case with impact data being sourced from unconventional sources such as news and social media, the overview presented here is most likely incomplete, as it depends on what people are willing and able to report and share online. Most of the located impacts occurred in Kralendijk (Figure 5). To some extent this may be expected, as exposure to the flooding is largest in populated areas. However, it could also reflect a reporting bias, as reports from flooding or other impacts are less likely to be made from areas that are not visited by many people. Nevertheless, it is clear that rainfall events like the one in November 2022 can have widespread impacts on Bonaire, leading to severe disruption and damage to infrastructure and property.

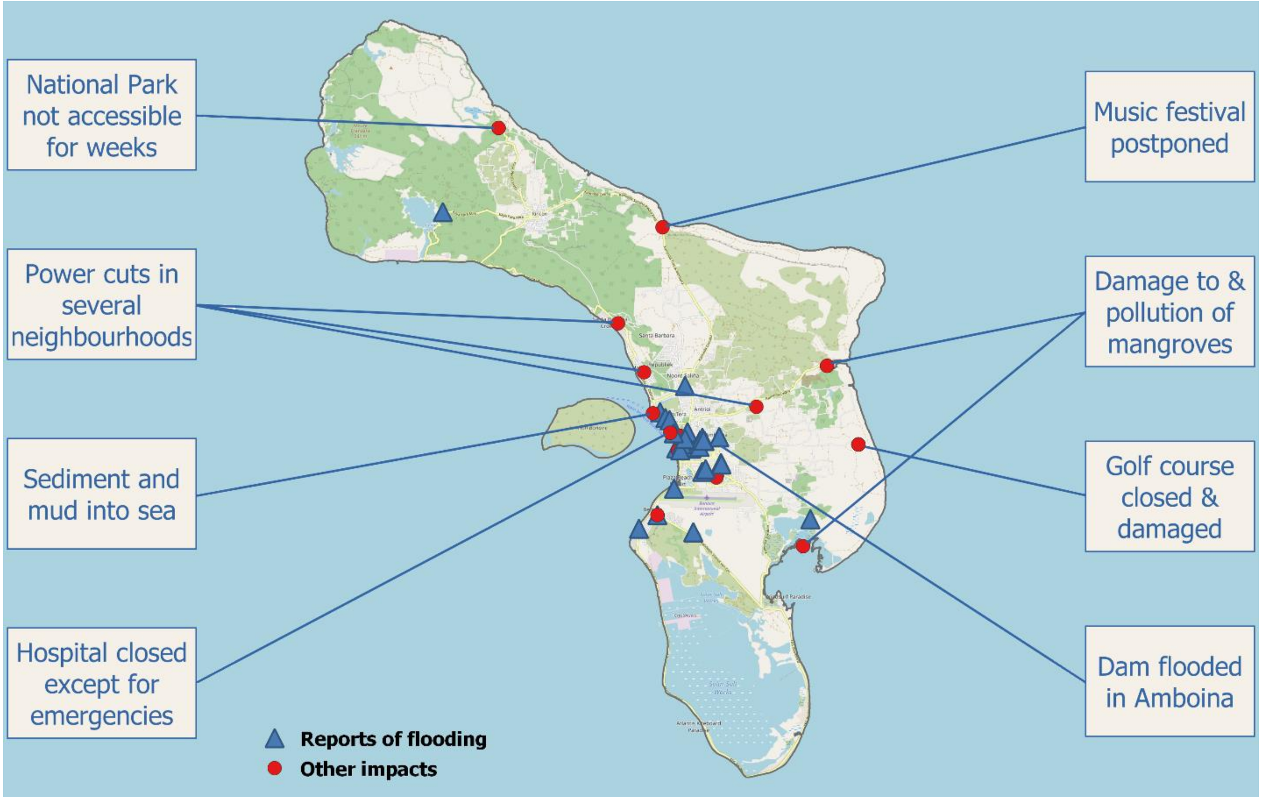

Figure 5 *Geographical overview of the impacts of heavy rainfall on 8 November 2022, as reported in news and social media.*

2.4 Projected climate change

Currently, there has been a declining trend in rainfall observed during the summer months in the Caribbean (IPCC, 2021; KNMI 2023). Although a negative trend in precipitation is also projected for Bonaire, this trend is not statistically significant and no significant positive or negative trend in precipitation has been observed so far (KNMI, 2021; KNMI 2023, IVM Institute for Environmental Studies, 2022).

Annual precipitation is expected to decrease by 2100 compared to 1986-2005 in all Intergovernmental Panel on Climate Change (IPCC) scenarios (Taylor et al., 2020). In the Caribbean region this ranges from -0.5% under the climate mitigation scenario SSP1-2.6. to -17% under the highest emissions scenario SSP5-8.5.

The KNMI’23 climate scenarios were presented on 9 October 2023 and provide four climate scenarios also for the BES-islands. These KNMI scenarios are built on the IPCC scenarios and provide key figures for the different climate projections (Table 2). The projections show that in the low-emission scenario (L), temperatures increase until 2050 and will then remain on the same level and also precipitation decreases slightly on the BES islands. In the high-emission scenario (H), temperature continues to rise and precipitation decreases more. Around 2100, there is stronger warming in the wet scenarios (n) and in the wet season, while difference is largest in the dry scenarios (d) and in the dry season. Furthermore, for Bonaire we see a stronger increase in wind speed in the dry scenarios and in the wet season (KNMI, 2023).

Storms are predicted to worsen with climate change. Stronger storms, in combination with Bonaire's coral reef degradation, can likely trigger an increase in surge-storm-related damages on Bonaire (Dutch Caribbean Nature Alliance, 2019). Additionally, flooding from rainfall and surges are expected to increase in frequency and intensity in the Caribbean.

The IPCC has expressed low confidence in a global increase in tropical cyclone frequency and intensity (Stephenson & Jones, 2017). Bonaire lies on the Atlantic hurricane belt's southern border and experiences tropical cyclones at a much lower frequency than the Dutch Windward Islands (Meteorological Department Curaçao, n.d.). Historically, the ABC-islands (Aruba, Bonaire, and Curaçao) have been considerably damaged by hurricanes about every 100 years due to heavy rains and rough seas that can cause flooding for several days (Meteorological Service Netherlands Antilles and Aruba, 2010).

Sea level rise poses a particular threat to low-lying Bonaire. At Bonaire, sea level is rising by 3.7 mm per year (approximately the world average). By 2050, sea level at Bonaire is expected to have risen by 14-34 cm (low emissions scenario) or 16-37 cm (high emissions scenario). By 2100, the rise ranges from 31-78 cm (low emissions scenario) to 55-127 cm (high emissions scenario).

Table 2 *The climate change key figures for sea level, temperature and precipitation on Bonaire. Wet season: May-November; dry season: December-April (data retrieved from KNMI'23 klimaatscenario's, 2023).*

Seizoen	**Variabele**	**Indicator**	**Klimaat (ref) 1991-2020**	**2050 (2036-2065)**				**2100 (2086-2115)**			
				Ld	**Ln**	**Hd**	**Hn**	**Ld**	**Ln**	**Hd**	**Hn**
Jaar	Zeespiegel	gemiddelde niveau	0 cm	+23 (14 tot 34) cm	+23 (14 tot 34) cm	+25 (16 tot 37) cm	+25 (16 tot 37) cm	+48 (31 tot 78) cm	+48 (31 tot 78) cm	+81 (55 tot 127) cm	+81 (55 tot 127) cm
	Zeespiegel	tempo van de verandering	4 mm/jaar	+2 (1 tot 6) mm/jr	+2 (1 tot 6) mm/jr	+4 (2 tot 8) mm/jr	+4 (2 tot 8) mm/jr	-1 (-1 tot 4) mm/ jr	-1 (-1 tot 4) mm/ jr	+11 (5 tot 24) mm/ jr	+11 (5 tot 24) mm/ jr
	Temperatuur	gemiddelde	28,5°C	+0,8°C	+0,8°C	+1,2°C	+1,3°C	+0,7°C	+0,7°C	+3,0°C	+3,3°C
	Neerslag	hoeveelheid	514 mm	-8%	0%	-15%	-2%	-7%	0%	-48%	-11%
Natte Seizoen	Temperatuur	gemiddelde	28,9°C	+0,8°C	+0,8°C	+1,3°C	+1,3°C	+0,7°C	+0,7°C	+3,1°C	+3,4°C
	Neerslag	hoeveelheid	346 mm	-6%	+2%	-13%	0%	-5%	+2%	-48%	-12%
Droge seizoen	Temperatuur	gemiddelde	27,8°C	+0,8°C	+0,8°C	+1,2°C	+1,3°C	+0,7°C	+0,7°C	+2,9°C	+3,2°C
	Neerslag	hoeveelheid	169 mm	-12%	-3%	-20%	-5%	-11%	-3%	-48%	-7%

3 Pathway to impact – from watershed to reef

The flooding in Kralendijk is not a phenomenon that occurs in isolation. It is the product of a combination of factors that all play a role: from the areas upstream in the local catchment to the water storage capacity of salt marshes (saliñas) in the urban area, the system of natural and seminatural rooien (channels), artificial dry river beds and drains, and finally the (lack of) water infrastructure in Kralendijk. Analysing this system and its hydrological, ecological and socio-economic components allows us to view the so-called 'pathway to impact' (Figure 6): the different successive stages leading from heavy rainfall to flooding, water quality issues, infrastructural damage and subsequent socio-ecological and economic impacts.

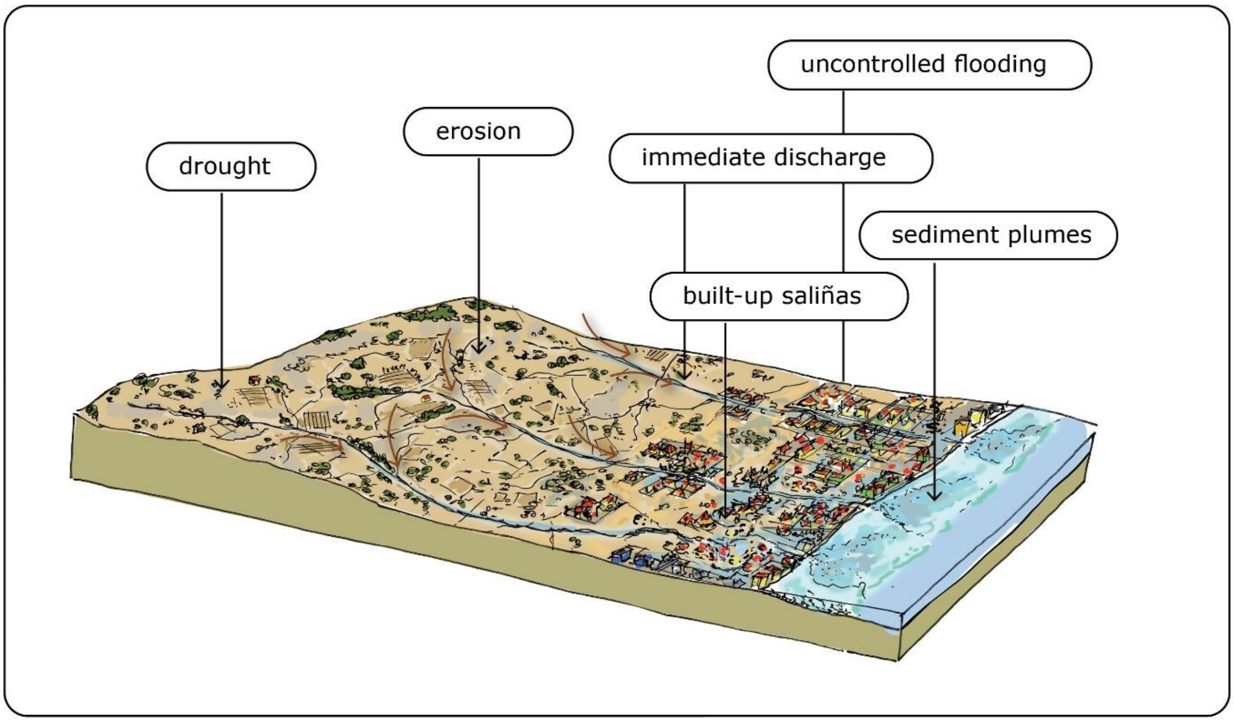

Figure 6 *Pathway to impact in the current situation. Upstream there is a lack of (healthy) soil and no absorption capacity that leads to surface runoff. High erosion rates are caused due to the lack of vegetation. Saliñas and other retention areas are under pressure downstream by built-up areas. A good water infrastructure is lacking and wastewater problems occur in Kralendijk. These up- and downstream processes increase the risk of flooding and bring sediment and sewage plumes into the sea, which negatively affect coral reefs.*

3.1 Limited water harvesting in kunukus

Ever since the arrival of Caiquetio Indians on Bonaire, water harvesting has been the main facilitator of agriculture on the island. Bonaire receives on average around 465 mm of precipitation per year, mostly concentrated in the rainy period between October and December. Retaining this water was a necessity to irrigate crops and provide fresh water for cattle on the kunukus. Kunukus is the general name used for the rural parts of the island, the areas located outside the urban parts.

The development of dams in dry river beds and later large water buffers ('tanki') on kunukus and plantations came to a halt in the second half of the 20th century following the changing socio-economic importance of kunukus. Much of the old water infrastructure in the natural and agricultural areas has either disappeared over time or has been damaged and degraded. Factors that complicate working on rooien and dams are the diffuse ownership of kunuku areas and the limited availability of knowledge on the location and status of water works in these areas. Knowledge is often limited to the experience of the (older generation of) kunukeiros (kunuku owners); some information is only mentioned in old, not yet digitized maps (Figure 7).

The absence of structures which retain water in the upstream catchment areas causes a sudden high discharge of water following rain events. The current storage capacity of the upstream kunukus is very limited and does not allow water to infiltrate into the soil or into limestone crevasses. This leads to risk of drought in the dry season, especially combined with the trend of salinization of ground water and wells (HHNK & Waterschap Limburg, 2022).

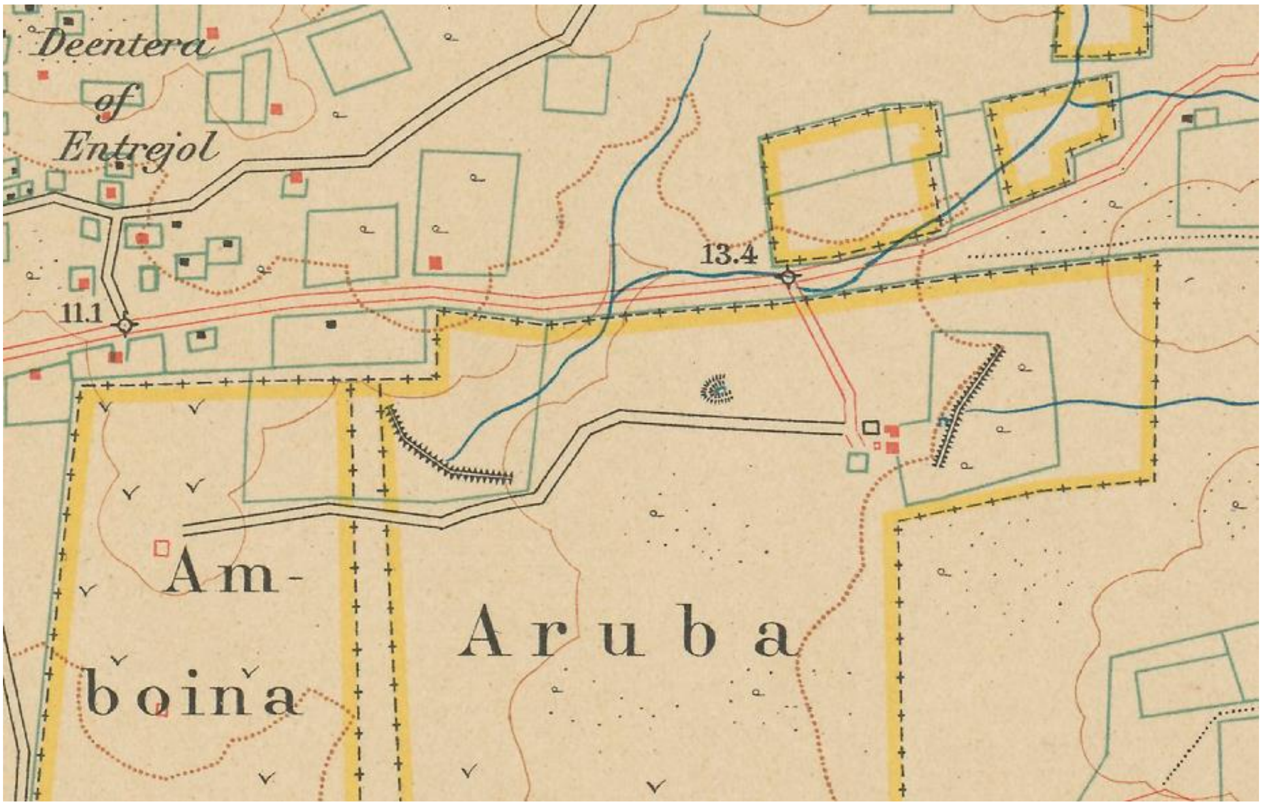

Figure 7 *Snapshot of historical topographical map of Bonaire with two dams to capture water from a rooi and a larger water buffer ('tanki'), both located in the area called 'Aruba' (Werbata, 1916).*

3.2 Poor vegetation quality in kunukus and natural areas

During the wet season on the island, water in the Playa catchment areas (Koster, 2013) cannot infiltrate in areas where heavy soil erosion has led to the (near) absence of topsoil. Heavy rainfall drops collide with the soil and loosen the earth. The rainwater cannot infiltrate and subsequently starts to flow down the hillsides, picking up speed as it goes and taking sediment along with it. Under ideal circumstances vegetation is able to prevent both rainfall from impacting the soil and flowing water from taking the soil with it. In the case of the kunukus, the ability of vegetation to reduce erosion is hampered by the grazing pressure of large numbers of free-roaming goats and donkeys, inhibiting the development of herbaceous vegetation and small trees. This leads to a monotonous vegetation dominated by cacti (mostly *Opuntia* and *Columnar*) and acacia shrubs with an underdeveloped or absent undergrowth, prone to erosion.

Many kunukus have been eroded to such an extent that the remaining soil has hardened, leading to a very poor infiltration capacity (BaaB & DROB 2019). A negative feedback loop develops: rainwater cannot infiltrate, vegetation development is slowed, erosion susceptibility increases, and the soil is further degraded.

The management of kunukus by their owners, kunukeiros, has changed over time. In the days of food production on the kunukus, maintenance was necessary to allow for crop planting and water harvesting. With the changing function of kunukus from production to recreation, maintenance of the kunukus has taken on a hybrid form in which kunukeiros often keep their kunuku 'clean', down to removing all vegetation to show only bare soil around buildings and facilities on the plot. However, animal keeping, crop production and water harvesting is not often practiced anymore. The name for natural vegetation on the island, 'mondi' in Papiamentu, is a synonym for 'messy' and is often seen as undesirable by Bonaireans. The practice of cleaning kunukus, sometimes executed with heavy machinery, increases the sensitivity of these areas and their surroundings for erosion and limits the possibilities for natural regeneration of vegetation.

3.3 Built-up saliñas

The saliñas (salt marshes) in the urban fabric of Kralendijk play a paramount role in the urban water system. During regular rainfall events, the saliñas fill up with water from upstream, allowing part of the suspended sediment to settle before flowing out into the sea. Historically, much of the Kralendijk area used to be saliñas behind the 'coral dike' (Figure 8); this is where Kralendijk derives its name from. The development of houses, offices and roads took place around the old Kralendijk, partly on top of the salt marshes, the flooding area around dry river beds, or even the river beds themselves. Many existing riverbeds have too little capacity for handling extreme rainfall events, either because of their dimensions or because of poor maintenance.

Several saliñas still exist in the urban areas and have not been developed because of unfavourable conditions for construction. Currently, saliñas have a dedicated designation in the Bonaire spatial plan (ROB). Their function of storing rainwater seems to be insufficiently protected to avoid future spatial developments in the salt marshes. Additional friction between the salt marshes and urban functions exists, demonstrated by spatial planning conflicts around Saliña di Vlijt. Initiatives for expansion of the neighbouring marina towards the saliña and permanently flooding the saliña to avoid dust and stench issues can conflict with the ecological and hydrological functions of the salt marsh. These developments have been subject to many reports and court cases in the past decade.

The buffering capacity of the saliñas in Kralendijk is thus reduced, leading to an insufficient settling time for the fine sediment carried with rainwater downstream during rainfall events, and to flood risk during heavy rainfall events. Locations where saliñas have been developed with buildings and roads frequently experience flooding.

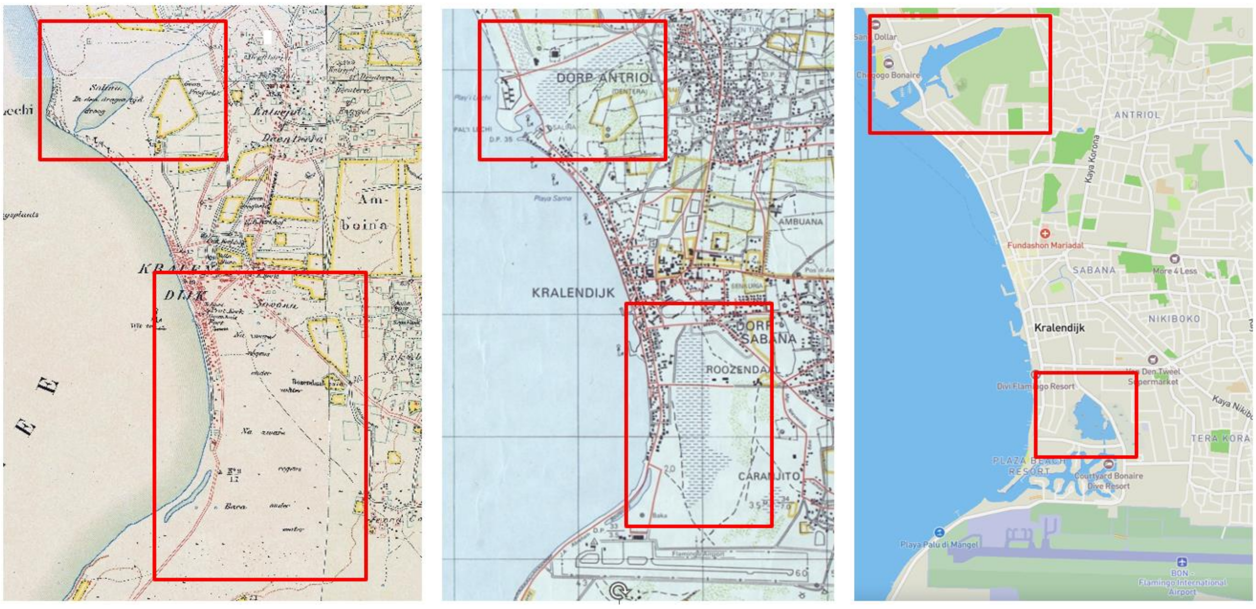

Figure 8 *Kralendijk and saliñas at three different snapshots in time.*
From left to right: 1911 (Werbata, 2016), around 1960 (TDN, 1960s), and 2020 (OSM, 2020).

Restoring the hydrological function of the Saliña di Vlijt was started in 2016 (BaaB & DROB 2019): part of the saliña was dredged and small islands have been formed in the north-eastern part. A follow-up to this project is in preparation; further dredging is needed to restore the water buffering and sediment trapping capacity. This needs to be done, taking into account the ecological functions of the saliña for wading birds, flamingos and aquatic life.

3.4 Lack of good urban water infrastructure

The urban water infrastructure in Kralendijk often lacks the capacity to drain rainwater and water from upstream to the sea during heavy rainfall (see examples in Figure 9). Three important rooien (channels) lead most of the rainwater out to sea: one between Saliña di Vlijt and Harbour Village marina, one between the southern saliñas, under Boulevard J.A. Abrahams towards the Marriot resort, and one rooi channelled underground beneath buildings and Kaya Debrot from Kaya Nicolaas to Kaya Craane on the shore (Kaya Debrot 72) (see Figure 10). Streets in between lack the facilities to lead excess water away without damage to the infrastructure, leading to damaged roads during rainfall events. Due to the geology of Kralendijk, additional water can well up from the groundwater during high tide. The lacking drainage in the urban area leads to flooding of streets and properties. Recently restored roads already show signs of water damage. In several neighbourhoods the paved roads lead water downstream when it rains, causing infrastructure damage and erosion.

Figure 9 *Examples of canalised, covered and overgrown rooien in the urban area of Kralendijk.*

3.5 Poor wastewater management

The last part of the impact that will be discussed in this report takes place on the private lands of Kralendijk. Here, rainwater mixes with wastewater before flowing out into the sea. The wastewater situation in Kralendijk has been the subject of many studies, projects and partial solutions. Part of the town is connected to a central sewage system which is connected to a wastewater treatment facility. However, most homes deliver their wastewater to a septic tank buried in the garden. The quality of these tanks varies, and no monitoring exists on waterproofness of the septic tanks. Together with the simple sewage pits present at many older homes this causes wastewater to seep into the calcareous stone below the houses where ground water is in direct contact with the sea. This background-level seeping of wastewater towards the sea is amplified during heavy rainfall, when wastewater mixes with the rainwater flooding streets and properties. Studies have shown that the fecal bacterial concentrations in the Marine Park spike after rainfall events (Francisca & De Wolf 2023).

3.6 A systemic view of flooding

When considering the problems of flooding in the urban area of Kralendijk, it becomes clear that we need to look at the system as a whole. The downstream areas in the urban fabric of Kralendijk are linked to the kunukus upstream. Rainwater that cannot infiltrate in the kunukus and that is not stored in the upstream areas of the catchments quickly runs down along the rooien. It brings along mud and debris into the lower reaches, where there is little space left to store the water and the sediment, and therefore causes flooding and damage. Mud and wastewater that is not able to settle in the saliñas will run off to the sea, causing damage to the marine ecosystem. When trying to solve these problems, simply taking measures downstream will be insufficient, impossible, or simply ineffective without simultaneously implementing measures upstream. It is clear that the natural, hydrological system has been degraded. NbS can help restoring this system and could allow for addressing multiple challenges at the same time ('co-benefits'). This will be discussed in the next section.

Figure 10 *Three main outlets for rainwater in the Kralendijk urban area. Map source: OpenStreetMaps.*

4 Solutions to urban flooding in Kralendijk

The problems following heavy rain events on Bonaire are the product of a series of cascading effects in the ecohydrology of kunukus combined with spatial planning issues and infrastructure shortcomings in the urban area. Tackling urban flooding and the impact of heavy rain on the Marine Park requires an **integral approach** of the 'catchment-to-reef' system. Reducing the amount of rainwater reaching the urban areas is needed to alleviate stress on the urban water system and reduce the flooding of saliñas and waterways – retaining more water in buffers and soil upstream is essential. However, without also reducing erosion upstream, the sediment load towards the saliñas will remain too high to effectively reduce sediment flowing out to sea. Infrastructural measures in town are the last step to alleviate flooding events and their effects on human health, property damages, society, seawater quality and coral reef health.

We propose a set of cohesive measures, ranging from large-scale ecohydrological restoration in kunukus and nature (green measures), down to infrastructural changes (grey measures) in town. We approach this challenge from a nature-based strategy, prioritizing working with natural principles and restoring regulating services of the natural system over solutions purely based in civil engineering. The result is a set of measures that not only alleviates water stress on Kralendijk, but also has a wide range of co-benefits to society, nature and economy.

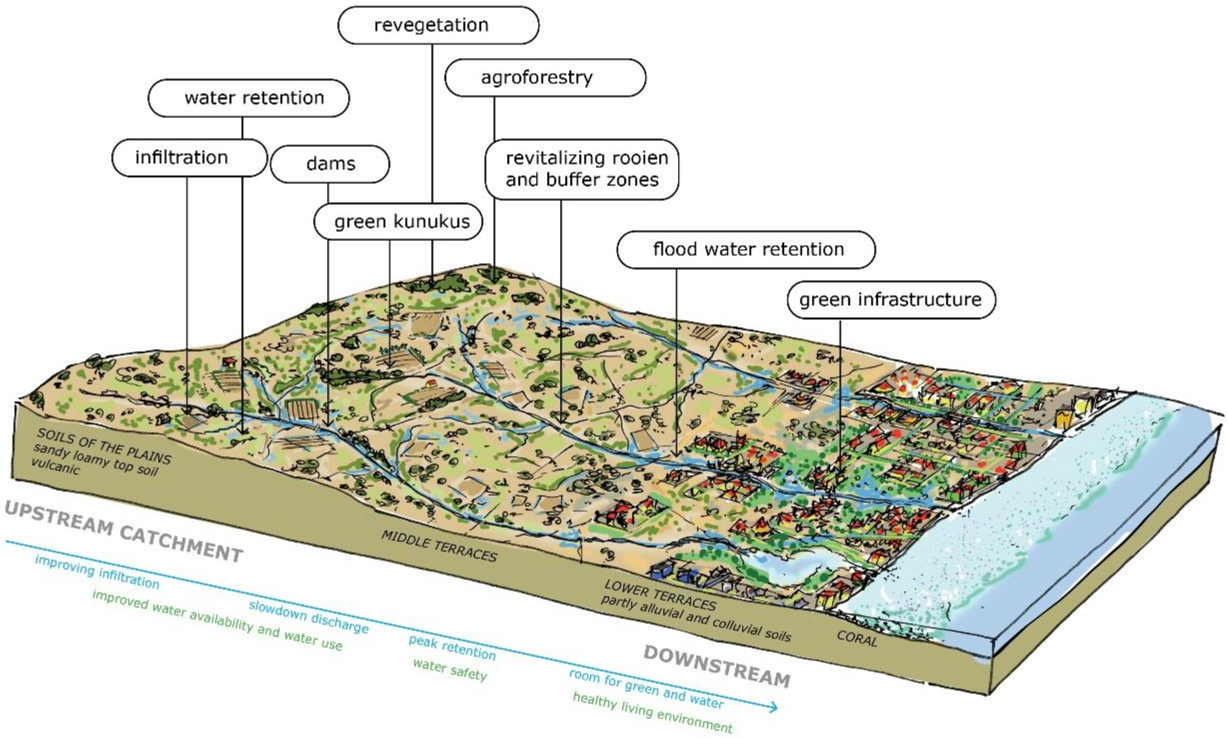

Figure 11 *Measures and NbS implementations to reduce the risk of flooding. Upstream revegetation, greening of kunukus and water retention help to improve infiltration and to slow down runoff. In addition, revitalization of rooien and buffer zones can slow down discharge and reduce flood peaks. Room for green and water creates a more safe and healthy living environment in the urban area of Kralendijk, downstream.*

4.1 Natural regeneration of upstream kunukus & erosion control

NbS can offer the upstream area of the catchment, which includes the lands used as kunukus, a twofold solution: retain rainwater and limit erosion. The following paragraphs detail how natural regeneration of the land can improve its water holding capacity and how this can be done in combination with (mostly) natural erosion prevention measures. The more natural regeneration is combined with erosion and impact prevention measures, the higher the chance of a successful improvement of the water cycle. All proposed measures are interventions that require thoughtful placement, dimensioning and coordination among stakeholders to work. In this report, generic measures are proposed for the kunuku areas; at a later stage specific measures could be set at specific locations based on careful investigation of the terrain and in dialogue with local actors. Figure 12 shows where the kunukus are located in the kralendijk area and differs between four types kunukus in use and in disuse. Tree cover on used and disused kunukus is colored differently.

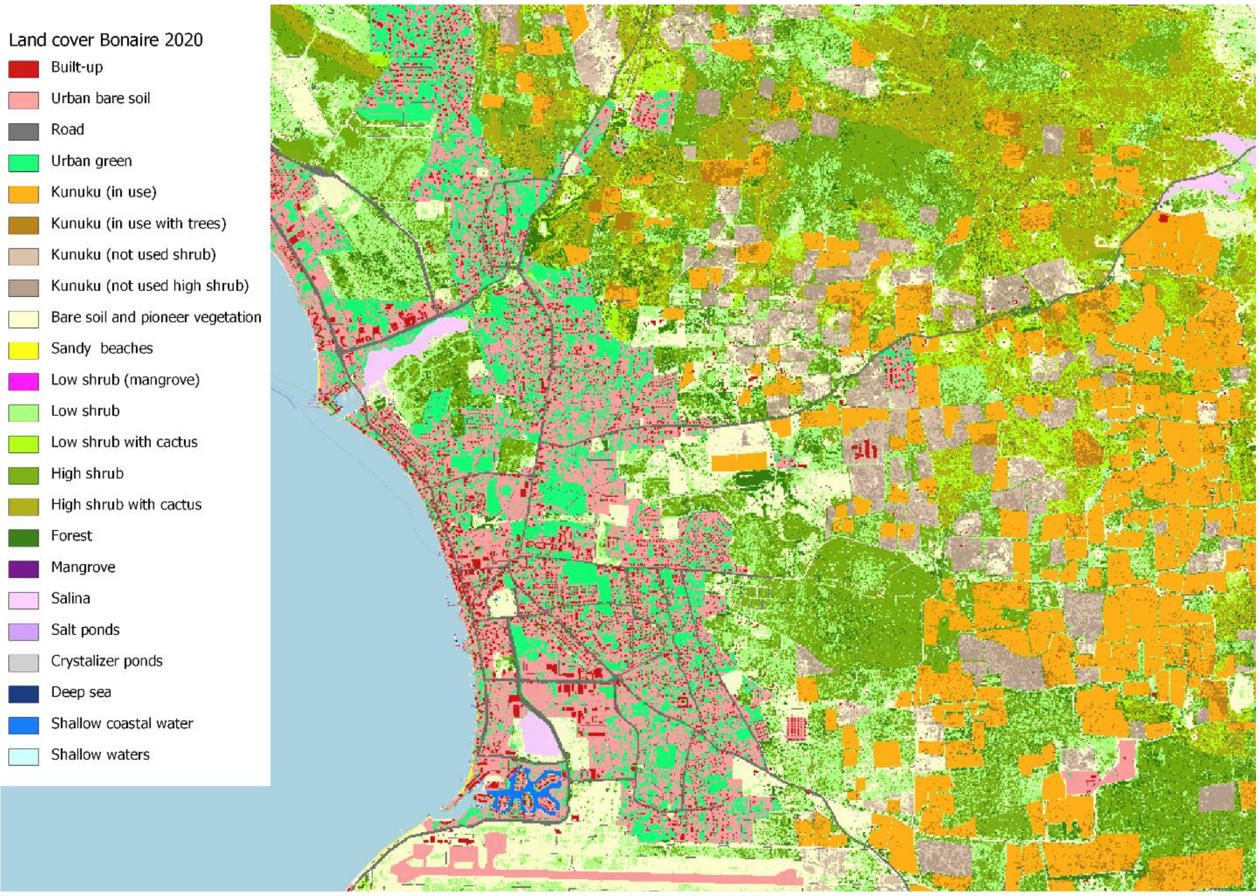

Figure 12 *Land cover map with urban areas and different types of kunukus on Bonaire in 2020.*

4.1.1 Land cover

This first section details the need for change in the cover of the land and a new perspective on agriculture. These recommendations are mainly relevant for the kunukus currently not in use (as depicted in Figure 12).

Recommendation 1: Remove and/or reduce immediate erosion threats
Grazing should be reduced and areas should be closed off (i.e., fenced). In order to break the feedback loop of soil erosion due to limited vegetation cover, the grazing pressure needs to decrease. By limiting goat and donkey grazing, natural regeneration of a more diverse vegetation can start. Fencing might be realized with living cacti or saddle trees as fence posts.

Recommendation 2: Keep in mind the importance of wild flora

Wild flora, which historically formed the pre-existing soil, are important for the regeneration of the land. The build-up of organic matter is a slow process that can be stimulated through the maintenance of ground cover and the replenishment of organic materials that are allowed to break down over time. Allowing a healthy undergrowth to be established among young trees can aid this process. A healthy (permeable, high in organic matter) soil can retain water much better than a degraded one. Areas where the topsoil has been completely eroded should be permanently covered with native vegetation, and livestock should be excluded until a certain stage of regeneration. Often, these areas are sloping lands which require labour to re-establish proper vegetation cover. Areas additionally afflicted by specific soil problems, such as compaction, can benefit from deep rooting vegetation ('rest' vegetation) such as perennial native grasses, grains, native clovers, or green manure. Such vegetation improves the soil health. Allowing natural regeneration of such areas will stimulate local biodiversity and improve the ecological functioning of the landscape. Research may be needed to establish which plant species will provide the best results under what conditions.

Recommendation 3: Stimulate natural regeneration or active reforestation

Reforestation is a well-known NbS. However, active reforestation can be intensive in terms of labour and resources. An opportunity could be available in the form of carbon and biodiversity credits, in line with climate change mitigation efforts. Existing business models can be explored to this end. Alternatively, by restoring local hydrology and reducing grazing pressure, the conditions for passive, natural reforestation can be set. Seeds and resprouts are essential ingredients of forest regeneration. These come from various internal or external sources, and together they determine the capacity of natural regeneration (Table 3). Natural regeneration of certain areas could be accompanied by active reforestation actions to achieve the best outcome – this is especially necessary when the capacity indicators of a certain area are low. Guidelines should be issued stipulating preferential local tree species, their planting techniques and their spacing requirements. There are already local organisations (e.g., ECHO, BonBerde and Tera Barra) that grow native species and specialize in reforestation using these seedlings. The results of large-scale regeneration in the tropics and subtropical regions has given varied results over a varied timescale. Chazdon and Guariguata (2016) highlight several cases of natural or assisted natural regeneration in which a 5% to 30% increase of natural area can be reached in a period of 5 to 20 years. Prieto et al. (2021) found that socioeconomic factors strongly influence the outcomes of natural regeneration. Banin et al. (2023) found, in a synthesis of Asian regeneration projects, that assisted restoration resulted in faster accumulation of tree mass (closer to old growth forest) compared to natural regeneration. However, they also found a high variability in outcomes across sites, indicating that planting for restoration is potentially rewarding but risky and context-dependent.

Table 3 *Indicators that predict the possibility of natural regeneration (adapted from Chazdon and Guariguata 2016).*

Indicator	Internal	External
Presence of topsoil and soil organic matter	X	
Soil seed bank	X	
Presence of rootstocks	X	
Abundance and cover of shrubs	X	X
Abundance of remnant trees	X	X
Abundance of animal-dispersed trees	X	X
Living fences / hedgerows	X	X
Local avian abundance and diversity	X	X
Local mammal frugivore abundance and diversity	X	X
Regional avian abundance and diversity		X
Regional mammal abundance and diversity		X
Remnant forest patches within 100 meters		X
Riparian forest patches within 100 meters		X
Large forest remnants or reserves within 200 meters		X

Recommendation 4: Seek a behavioural change regarding the perception of 'mondi' (messy vegetation)

The practice of managing kunukus by removing most vegetation increases erosion risk and does not allow for soil building. Often this practice, rooted in preparing the kunuku for crop growing and water harvesting as mentioned before, is done because of old habits and does not serve its original purpose anymore. To do away with a practice is also to start a new practice, based upon a new perception, or ethic. This new ethic can be seen as being rooted in a cultural historic ethic, since the land was historically used more sustainably (before the onset of the off-island oil industry and tourism). A new land ethic developed through a social process could prove useful. Such an ethic could be seen as guidance for improving the current ecological situations, which are so intricate that the desired path is not always discernable for the individual kunukeiro. The shift would include a new management style of the vegetation and the soil. This land ethic could reflect the collective ecological conscience of the kunukeiros in their responsibility for the health of their own land and island. It would include a broader value of the land than currently exists, encompassing: the capture of water and prevention of downstream flooding, the increase of local biodiversity and land health, and climate change mitigation through carbon sequestration. This process can be set up parallel to existing ones and inform the new spatial plans set out in the official nature and environment policy plan (Natuur en milieubeleidingsplan Caribisch Nederland 2020-2030).

Recommendation 5: Develop agroforestry and other regenerative practices

Developing agroforestry (e.g., syntropic farming, see Figure 13) and other regenerative practices could enable sustainable small-scale food production and improved water retention. This is especially relevant for the kunukus currently in use. The few kunukus in the Kralendijk area that do have a lot of trees (see Figure 12) could potentially be used as examples, showcase farms where the practice is taught. Food production on kunukus is getting scarcer. Efficiently producing food crops is a labour-intensive job – one of the reasons kunukus are rarely used for large-scale food production. The kunukeiro needs a new perspective. Small-scale food production for the family is possible on many kunukus, but require a type of agriculture based on water and resource availability and local nutrient cycles. By showcasing the possibilities for small-scale permaculture, agroforestry and landscaping for kunukus (e.g., by building terraces surrounded by levees to retain more water), an attractive usage of kunukus can be promoted. It is possible that kunukeiros need help realizing these practices in terms of knowledge exchange, planning or executing projects, and financing of investments. It is essential that land owners are taken along in the process of development and decision making so that they feel ownership of the solution, since management will be carried out primarily by them. A viable business model should be discussed and evaluated.

Figure 13 *Left, a snapshot of syntropic farming at Mangazina di Rei. Right, levees on kunukus to retain water in the wet season. At the bottom right, goat and sheep dung fertilizer can be seen. Picture taken in the dry season.*

4.1.2 Water harvesting and retention

This section highlights measures that can be taken to catch and retain water (see also Figure 13). Retained water can improve the groundwater flow and thus aid the hydrologic cycle of the island. It can also be used for regenerative measures. At a later stage this water can be used for new types of land use, including new forms of sustainable agriculture. These measures are relevant for all kunuku types, both in use and in disuse.

Recommendation 1: Restore and/or create water buffering capacity of dikes and rooien
With small to medium scale measures, uphill water buffering can decrease the amount of runoff that reaches Kralendijk all at once during a rain event. The storage capacity of dikes has been greatly reduced due to neglected maintenance. Possible measures for the dikes include dredging and clearing of undesired vegetation to improve the capacity and reinforcing earth walls (if present). Additionally, new depressions where the water can accumulate can be dug or build – this would require a good digital elevation model of the island, which doesn't exist at the moment. The buffering capacity of dikes relieves pressure on the civil infrastructure of Kralendijk, while increasing the retention of water upstream. Measures for the rooien are mentioned in the next section on erosion control.

Recommendation 2: Implement small scale water harvesting measures in combination with reforestation
Historically, water retention was practiced on the kunukus; this historic local practice can be reinstated to improve the possibilities for food production while facilitating natural regeneration and reforestation. Downstream, it will decrease flooding and reduce the degradation of lands. Measures can include land use management practices derived from more arid zones like 'half-moons', 'planting pits' or 'fanya juu' (terracing terms), combined with reforestation actions, as seen in the top-right corner of Figure 13. These measures would aid the planting of trees without drip irrigation since water will be infiltrated on the spot. They must be implemented with care and preferably in combination with other field measures to prevent a collapse during a heavy rainfall event. Mulching the saplings with cuttings of undesired species can aid in retaining moisture

and reducing the presence of these species. Note that goats and donkeys should strictly be kept out of newly reforested areas since they prefer young saplings for their feed.

Recommendation 3: Improve infiltration capacity by using the appropriate ground cover
The use of deep rooting species is recommended where topsoil loss has led to hardening or compaction has led to impermeable soil layers. In the case of soils with limited aggregates, species should be selected that have a fibrous root system to hold soil particles together. A mix of tree species with deep roots and grasses with intense fine roots results in the highest soil stability on slopes.

4.1.3 Erosion control

This section details erosion measures according to where the measures intervene in the erosive process: prevention, control, or impact reduction. These measures are relevant for all kunukus, both those in use and those in disuse.

Recommendation 1: Implement terracing
For the kunukus that are not permanently reforested, there should be a (re)implementing of terraces, especially for those kunukus that historically have been terraced. Terracing reduces the slope and thus the speed of the water, which, in turn, dampens the erosive capacity of the water. These terraces should be sloped correctly to function under the current and predicted future rainfall amounts. Perennial vegetation (hedges, trees, grasses, perennial crops) should be planted on the terrace contours and on contour lines to act as a permanent but permeable break for speeding water. Contour bunding can be practiced by using stones in places where vegetation does not yet grow due to poor soil/water conditions. Note that contour bunds should be continuous to be truly effective, meaning farmers with adjacent plots will have to work together to agree on their construction/placement. Permeable barriers often are preferred to impermeable ones since landslides are less likely to occur. Historical terraces on limestone may have a fertility gradient (low fertility at the top of the terrace, high fertility at the bottom), which could be remedied by using green manure crops. The disuse of the kunukus hampers collective work on erosion prevention as without use there is little direct incentive to the individual kunukeiro to implement these measures on their kunukus.

Recommendation 2: Establish vegetation on drainage pathways in fields
In places with persistent drainage, especially on steeper slopes, permanent native grass can be used to create grassed waterways, as seen in the bottom-right corner of Figure 14. Grass (or similar rooting vegetation) with high erosion resistance consists of a closed vegetation with a high root density in the subsurface layer of 0-15 cm. Achieving a closed grass field and dense rooting depends on both proper management and the soil properties. Using vegetation in the drainage pathway is especially beneficial as the vegetation will grow in the rainy season and thus reduce the speed of the water the most in the period with the most rainfall. Grassed waterways are most effective on slopes <20%, unless drop structures are used. Grassed waterways have been researched since the 1940s and have been applied across the globe. The WOCAT database (the World Overview of Conservation Approaches and Technologies) provides a few examples (Norway, Kenya). Knowledge on the topic has extended ever since, and has more recently been adjusted to account for local vegetation characteristics. In 2005 the USDA recommended 16 species for grassed waterways in Puerto Rico (PREQB & USDA, 2005), which could also be used on Bonaire. This was recently improved by Silva-Araya et al. (2023).

Recommendation 3: Establish vegetation in rooien
Vegetation cover, similar to the previously mentioned grassed waterways on the fields, should be grown in rooien. This riverbed cover needs to be mowed and maintained so that it does not block the water when drainage is urgently needed. Fencing the rooien is desirable and would allow for the colonization of a dry riverbed by terrestrial vegetation after a rainfall event. This would greatly contribute to river channel health and local biodiversity. Simultaneously, fencing the rooien would hinder free ranging goats and donkeys from easy upstream and downstream travel through the dry riverbeds. These measures could be combined with increasing the size of the rooien to maintain drainage capacity and improve riverbed health.

Recommendation 4: Prevent the development of undesired waterways, such as gullies
A gully is a landform created by running water, which sharply erodes into soil, typically on a hillside or terrace; they often resemble miniature valleys. Gullies are commonly related to intermittent water flow and usually associated with local high rainfall events. Gullies produce sediment that may fill downstream saliñas and reduce water quality in the coastal system. When gullies form, the on-field vegetation measures need to be implemented urgently in order to retain the water where it falls. Additionally, to reduce the erosive power of the gully, a gully plug (or check dam), constructed out of local vegetation, can be implemented, using materials such as acacia branches, tree trunks or cacti (if possible). Guidelines can be issued on how to implement this measure, as incorrect placement or construction can lead to collapse and a landslide-like debris flow. Forms of gullies have existing for a long time around the world and existing information was bundled into a technical guideline by the FAO (Geyik, 1986); others have extended this knowledge into, for example, textbooks (Singh, 2023).

Recommendation 5: Prevent sedimentation in undesired locations
Retention areas where peak water discharge can be retained can also be used to prevent sedimentation of eroded materials further downstream. As addressed in the next section, urban saliñas can play a role in the retention of silt. It is, however, also a possibility to implement retention measures further upstream in the terraced landscape, for example by creating temporary natural ponds in which sediment can settle for the duration of the water retention, resembling a sand-trap. Reducing the speed of the water upstream can form the basis of the solution to reduce sedimentation downstream. Permanent vegetation, improved infiltration and reduced runoff all add to this success.

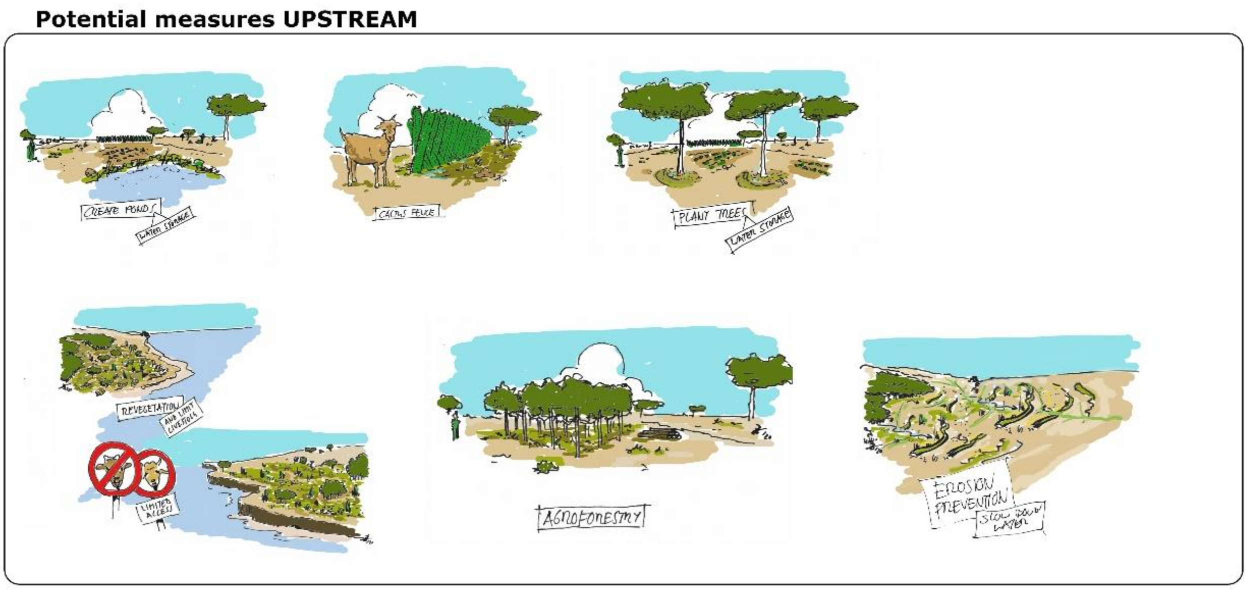

Figure 14 *Proposed NbS measures in the catchment.*

4.2 Protecting the urban Saliñas

Further downstream, the saliñas that still exist offer the potential of a NbS to flooding issues in Kralendijk and sedimentation in the marine environment. A number of measures need to be taken to strengthen this function of the saliñas (Figure 14).

Recommendation 1: Implement stricter enforcement of not building in saliñas
Saliñas are currently designated in the Spatial Development of Bonaire (‘Ruimtelijk Ontwikkelingsplan Bonaire’ – ROB), but building activities in the water buffering areas are still common. Protecting the last functional saliñas in the urban area of Kralendijk needs to be internalized in local governance. Education and communication can help the private sector acknowledge the important ecosystem services the saliñas

provide and hopefully counter the 'nuisance' arguments that are used to initiate projects that threaten the saliñas water buffering and other ecological functions. A business could be built for the protection of the existing saliñas. Perhaps this could be done based on tourist activities.

Recommendation 2: Continue regeneration and silt removal of Saliña di Vlijt
In 2016-2019 some measures were implemented to remove silt from Saliña di Vlijt and to increase its buffering (water retention) and silt capture capacities. This project can be extended, further restoring the natural functions of Saliña di Vlijt to efficiently capture more sediment and to retain more rainwater in the wet season. Silt removed from the saliña is a valuable resource (e.g., as building material) which could offer a business case for the operation, as in the case of Millingerwaard in the Netherlands.

Recommendation 3: Foster the natural regeneration of mangroves
During digging in Saliña di Vlijt, evidence was found of historic mangrove growth in the saliña. Restoring mangrove growth could help sediment trapping and increase biodiversity of the saliña.

Recommendation 4: Protect the ecological functions of saliñas
Not all measures related to water buffering are beneficial to biodiversity. Fluctuating water levels in the saliñas play an important role for waders and other shorebirds. Outcomes of measures changing the land-water transitions in saliñas need to be carefully evaluated for effects on biodiversity.

Figure 145 *Creating natural dams and retention areas, revitalizing rooien and buffer zones, preservation saliñas.*

4.3 Solving infrastructural bottlenecks in Kralendijk

Within the urban area of Kralendijk, a number of measures could help solving some of the impacts that have been observed during recent flooding events. Infrastructural measures in Kralendijk are meant to alleviate water stress during peak rainfall events. Improving these bottlenecks without taking measures upstream will not effectively solve urban flooding risks, as the amount of water from upstream areas could be too large for the capacity of the urban water system.

Recommendation 1: Build roads with drains and culverts
New constructed roads are often without proper drainage facilities. More attention to the scenario of a wet season or extra heavy rainfall could avoid future infrastructural damage. There should be strict prohibition of building projects where rooien are being backfilled; creating culverts with sufficient capacity where rooien underpass roads is essential for upkeep of the urban water infrastructure.

Recommendation 2: Increase capacity of urban rooien and culverts
In built-up area of Kralendijk, many rooien do not have sufficient capacity to carry the high rainwater flows during most of the wet season. By creating more space for rooien, either by a broader profile or by tackling bottlenecks (e.g., too-small culverts), the capacity for drainage in exceptional wet situations can be enlarged.

Recommendation 3: Maintenance of rooien
Existing rooien are often not maintained well; illegally dumped materials and encroaching shrubs and plants limit the water flow at peak moments. The rooien that are important for draining the urban fabric need to be well-maintained.

Recommendation 4: Restore rooien that have disappeared
During building activities, rooien are sometimes backfilled. By restoring former rooien, drainage capacity during peak rain events can be increased.

It is important to note that infrastructural measures in Kralendijk are meant to alleviate water stress during peak rainfall events. Tackling these bottlenecks without taking measures upstream is not likely to effectively solve urban flooding risks, as the amount of water from upstream areas could be too large for the capacity of the urban water system.

4.4 Adapting housing to climate change

In addition to infrastructural measures, a number of measures could also be taken by developers and individual households to reduce problems associated with flooding and pollution (Figure 15).

Recommendation 1: Ensure that project development is water-robust
Knowledge about unfavourable building sites (saliñas) needs to be shared within the housing sector. Furthermore, plots and urban design for new developments need to be designed in a way that takes rainwater into account. An instrument similar to the 'watertoets' (water check) in the Netherlands could be used to have developers proactively research and report on the effects of their development on the local water system. This could help to avoid future flooding of the plot or redirection of flooding to neighboring areas.

Recommendation 2: Encourage greener gardens
Private property owners can contribute by greening gardens, countering the trend of removing all vegetation around the house. Contributions from single houses to the environment of larger buildings can help alleviate urban flooding. Government could implement a voluntary programme to remove tiles and replace them with vegetation, maybe reducing the taxes on the property or water management for the households who join the programme.

Recommendation 3: Encourage rainwater harvesting on building scale
Historically every building on Bonaire had facilities to harvest and store rainwater, usually in an aboveground cistern (Figure 16). These constructions can still be recognized in older buildings by the characteristic overflow exits or gutter structures leading water to the cistern. On Saba, buildings used to be built with an underground cistern for rainwater harvesting, usually used as a greywater system. Harvesting rainwater would mean a small contribution to flood risk reduction, but is meaningful in the light of reducing energy-intensive desalinized water usage.

Recommendation 4: Improve wastewater management
The ongoing implementation of centralized waste water collection and treatment, paired with initiatives promoting decentralized wastewater treatment (Water Circles) are necessary to improve wastewater facilities on the island. The use of cesspits, as well as unregulated older septic tanks, needs to be phased out in order to: protect groundwater quality, prevent wastewater seeping out into sea via ground water, and limit human health risks associated with wastewater seeping out to sea.

Recommendation 5: Encourage innovation in the real estate development sector
This sector can take inspiration from Bonaire and beyond. Existing policy on inventory of environmental values and barriers on building location needs to be adhered to, enforced, and possibly extended to smaller building sites.

Recommendation 6: Cultivate collective responsibility of suppliers, developers, designers, consultants and, of course, the clients

These parties should take responsibility for facilitating sustainable building practices such as rainwater harvesting, greener gardens, and reducing soil sealing. When beginning development, there should be no more ‘cleaning’ (removal of natural vegetation) from an entire building plot but only where the infrastructure needs space. (Note: this is already practiced by several smaller real estate agents.) There should also be better compliance with policies prohibiting building in saliñas and rooien. Rainwater and wastewater management is needed to put existing policy into practice regarding this. Sharing good practices on water-smart spatial development can help actors build climate resilient properties and neighbourhoods.

__Figure 15__ Rooftop water harvesting and storm water harvesting can help to reduce urban flood risks. In addition, the water that is collected can be used during dry spells.

__Figure 16__ Example of water harvesting on roofs on Bonaire. The three white openings in the wall are overflows in case of water storage limitations.

5 The next steps towards reduced flood risk and improved climate resilience

In the previous sections we have outlined a number of NbS that could help in reducing the problems associated with flooding, sedimentation and pollution in Kralendijk and in the marine environment. These measures come with a number of co-benefits such as regenerating the kunukus and improving the biodiversity on the island. To implement these measures, a number of actors need to come together, and a number of steps need to be taken. We recommend embedding these in a transition process with local stakeholders. Implementing the recommended measures without such a process will most likely lead to undesirable results, as measures are likely to be insufficiently realized. Transition design is inspired by the need for design to be more reliable in the face of increasingly complex problems. The issues on the island are the result of a complex system of actors in a natural landscape historically tied to colonization by the Netherlands. Climate change and urgent biodiversity loss press for an integral solution. We propose that the measures discussed in the previous sections be implemented as part of such a transition design process. We will formulate the recommended steps as building blocks for such a transition design process.

1. Start with further improving the understanding of the natural and social system (under change), including its complex problems.
   - Currently, research is being conducted on Bonaire's hydrology. More detailed knowledge on catchment areas and water flows, combined with climate scenarios, can help in properly dimensioning water infrastructure to certain weather events. However, essential datasets that aid spatial development and scientific developments are missing for Bonaire, e.g. a high-detail digital elevation model (DEM) and a detailed land use map.
   - Further understanding of the island's natural system, including soil properties and the presence of native species, is needed to effectively implement measures. Further research will be necessary on the effectiveness of specific NbS and their implementation, as well as where they could best be located.
   - Kunukeiros have a role in the current erosion issues and should be part of the solution. We must understand their history, perspective and future prospects.
2. Create the boundary conditions for collective change. Living through change requires collaboration and openness. Trust and coherence among stakeholders and government bodies is necessary.
   - Invest in a stronger local government. A combination of strong political support and financial support from the Dutch national government could be a starting point for effective resilience action by OLB ('Openbaar Lichaam Bonaire', Public Body of Bonaire). Implementing measures depends on a strong government. This also means an increase in efforts of licensing, monitoring and control. Political will is needed to implement existing good policies and to prevent other interests from subduing environmental action.
   - Push to align and strengthen coherency of policies, agendas, strategies, actions and efforts of OLB, NGOs, businesses and other local actors.
   - The measures proposed in this report can inform a proposed climate dialogue ('Klimaattafel'), specifically on the topic of climate adaptation, and vice versa.
   - Spatial plans should explicitly state the water retention infrastructural elements and required building regulations.

3. Co-create long term futures that are sustainable, equitable and desirable. This should inform measures in the present that can act as steps along a transition pathway.
   - Wageningen University has recently developed a study titled: 'A nature inclusive vision for Bonaire in 2050', which can be used as a starting point, combined with the findings of report in the readers hands. Policy developments on the island such as 'Natuur en Milieu Caribisch Nederland 2020-2030' and the proposed climate dialogue can inform a societal debate on a desirable future. This should at least include:
     - The societal dialogue on free-roaming grazers, taking into account the negative effects on soil, water and nature as well as the societal and cultural importance of cattle herding for kunukeiros. Although this echoes the many earlier advices from consultants and scientists, it is also a crucial element in battling flood risk.
     - Strategies on (collective) soil and water management, informed by a new conscience of the land ('land ethic'), as the current issues are an extension of the current (mis-)use of the land. This should also encompass broader benefits of nature, new farming systems, and new business cases.
4. Start designing in new ways. Measures should solve multiple issues simultaneously and aim to span years or even decades.
   - Inspiring good practices on the island is needed to provide a future for kunukeiros. Develop a new land ethic and new business models in collaboration with local stakeholders who will implement measures.
   - Gain insight in the old water infrastructure ('dammen', 'rooien', 'tankies' – dikes, waterways, ponds), and improve collaborative action towards collective water management. Together with stakeholders and experts, locations can be sought to implement the proposed measures.
   - Adapt and implement the proposed measures together with local organizations. Organize long-term maintenance in policy and practice.

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