EcoVision
Environmental consultancy and management

Report:	**Environmental Impact Assessment (EIA) for the harbor construction at Black Rocks, Saba**
Status:	Final report
Principal:	Openbaar Lichaam Saba
Date:	June, 2022
Our reference:	P20/ECO.624 and P20/ECO.648
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Summary

Introduction

In 2018, EcoVision prepared an Environmental Impact Assessment (EIA) for the harbor reconstruction of Fort Bay Harbor by assignment of the Public Entity of Saba (OLS). This reconstruction was required following the damage caused by hurricanes Maria and Irma to the Fort Bay Harbor. Funding was made available to repair and upgrade the existing harbor and make it hurricane and future proof. The preliminary designs were completed in 2018 based on building a new secondary breakwater and an extension of the primary breakwater to provide a sheltered and safe harbor. Validation of the design was carried out in a physical scale model for regular and extreme (category 5) hurricane conditions. The results demonstrated that the hurricane wave impacts, especially for the primary breakwater, could be extremely high. This is caused by the very steep foreshore and large water depths directly in front of the Fort Bay harbor, which causes 15m high waves to break directly onto the extended breakwater structure resulting in very high impulsive wave loads.

These findings fueled a discussion about the merits of investing significant amounts of money in the existing Fort Bay harbor when there would remain a substantial risk of severe damage or even collapse during hurricane events.

A feasibility study was carried out in the period May - Sept 2019 looking at an alternative location further east along the coast in the so-called Giles Quarter / Black Rocks area (Plas, van der, 2019). This study indicated that at this location hurricane wave heights would be significantly less due to the gentler foreshore. The shallower waters also allow construction of a harbor closer to the shore at reduced cost and risk. The topography offers substantial benefits over the Fort Bay in the sense that it is flatter and gentler and offers more space for landside (harbor) developments, both now and in the future.

From a viewpoint of harbor development, the Black Rocks area has a number of advantages compared to Fort Bay:

- shallow water and thus gentler wave conditions during hurricanes, greatly reducing the risk of severe damage or collapse of key harbour infrastructure
- a safer and much more sheltered harbour for the local fleet, ferries and visiting yachts
- more useable space for future expansion
- possibility of a future 2nd access road from the villages to the harbour, avoiding the dangerous Fort Bay road
- availability of land for future development
- new architecture may be attractive for tourists
- land ownership is more straightforward

Disadvantages or challenges are:

- it is a greenfield project
- risks with road connection
- higher investments

Early October 2019, formal approval was given by the steering committee, consisting of members of the Executive Council of the Public Entity Saba and representatives of the Dutch Ministry of Infrastructure and Water Management, to advance with the site investigations, design and impact assessments for the Black Rocks Harbor.

OLS asked EcoVision to produce an Environmental Impact Assessment (EIA) for the harbor at Black Rocks. This EIA is a document aimed to support the decision making for the harbor construction project. It is a legal obligation based on the Law on maritime management BES and the Saban Ordinance on the marine environment.

In this EIA, environmental impacts of the construction of a new harbor at Black Rocks are evaluated. Normally, location alternatives are also incorporated in an EIA. The initial harbor project, the upgrading of Fort Bay harbor, cannot be seen as a real alternative for the Black Rocks harbor because it is demonstrated that an upgraded harbor at Fort Bay is less safe and less hurricane-proof than a harbor at Black Rocks. For this reason, this location alternative is not included.

However, the previous performed EIA for the Fort Bay harbor (EcoVision, 2019) indicated less impact on nature and environment than the harbor at Black Rocks. Therefore, it is decided to include a summary of the EIA of reconstructing the existing harbor at Fort Bay, including a comparison of the EIA results of an upgraded harbor at Fort Bay and a new harbor at Black Rocks (See Annex 15).

Objectives

The objectives of the EIA are:

- to assess the natural values in the projected harbor area (both marine and terrestrial);
- to assess the environmental situation in the projected harbor area (both marine and terrestrial);
- to assess the environmental and ecological impacts of the construction of a new harbor at Black Rocks;
- to define mitigation measures for these impacts;

Main features of harbor construction project

In environmental and ecological terms, the construction of a new harbour at Black Rocks can be characterized as a "greenfield development". No commercial or industrial or other structures are present in the area, which is a natural grass- and shrubland area with trees interspersed.
The main elements of the harbor construction project are:

- the extension, renovation and paving of an existing dirt road between Fort Bay Harbor and Black Rocks, including connections to current infrastructure;
- the construction of gabions for water management, north of the projected harbor area;
- the construction of a breakwater and quays;
- the dredging of the harbor to specified depth;
- the construction of harbor facilities.

Environmental impacts from these activities have been evaluated in this EIA for the base case, which is a so-called rock berm breakwater. In addition, impacts have been evaluated for two alternatives with smaller footprints: a caisson structure and a cofferdam structure[1].

Present environmental situation

Erodibility in the southern watershed areas is extreme to very extreme, which is probably related to the presence of goats in this part of the island. The maze of unpaved roads and the aggregate quarry are also important contributors to erosion.
Especially unpaved roads promote extreme erosion, which is estimated to be 10.000x times higher than in natural, vegetated areas. Several landslides have occurred south of St. John's, just north of the current unpaved road to Black Rocks, leaving a very unstable and erodible top layer.
The present extreme situation with respect to erosion requires urgent action.

[1] Construction with piles and sheetpiles, for which pile driving is needed

For Saba no historical data with respect to water quality are available (e.g. suspended solids concentration SSC), affecting light penetration in seawater. According to Hildebrand (2017) mean visibility in water (using the Secchi disk) over 20 dive sites was 27.5 meters, which is relatively high compared to other Caribbean sites (Jackson et al., 2012). In the period from August – November 2021, measurements of currents (ADCP) and light penetration (with OBS) have been conducted at the site. The results are presented in Annex 14.

Main ecological values

The main ecological values (terrestrial and marine) at Black Rocks-Giles quarter are:

- the likely presence of 32 rare plant species in the proposed project area, based on the Landscape Ecological Vegetation Map of Saba (De Freitas et.al., 2016);
- the presence of endemic and endangered plant species in the proposed project area;
- the presence of more than 300 trees in the vegetation survey area, of which 30 in the proposed project area;
- the presence of a relatively large forest of manchineel trees about 200m north-east of the projected harbour;
- the presence of a colony of red-billed tropicbird in St. John's Cliffs;
- the presence of breeding Audubon's shearwater in St. John's Cliffs;
- the designation of the coastal area as an internationally recognized Important Bird Area;
- the presence of three iguana species, four lizards and one snake with high conservation status;
- the relatively rare stands of the protected coral species of *Acropora palmata* in and near the footprint area;
- the presence of other colonies of protected coral species, mainly *Orbicella annularis* and *Orbicella faveolata;*
- the presence of several patch reefs and seagrass beds near the footprint area.

Impacts and impact mitigation

The construction of a completely new harbor in a currently undeveloped nature area (a so-called "greenfield" development) is anticipated to produce environmental and ecological impacts. A substantial number of these impacts can be mitigated to the extent that their residual impact is acceptable ("moderate" or less). However, a number of impacts remain at a level qualified as "significant", or even "severe", after impact mitigation. These impacts are:

Terrestrial impacts:

- Loss of ecological values in the terrestrial footprint (roads, weirs, harbor area): 40.000 m2, of which 22.000 m2 is largely vegetated and needs to be revegetated[1]. The coastal area is designated as an Important Bird Area (IBA). The grass and shrub vegetation (mainly a Aristida-Mitracarpus vegetation type) is common for the south part of Saba. The vegetation shows signs of disturbance, mostly by goat grazing, but it likely harbors many rare species and species of high conservation importance. The area is functioning as a relatively undisturbed nature area and it supports a variety of ecosystem functions, such as a hydrological function (major gutter) and a recreational function. The vegetation itself plays a very important role in limiting erosion and sedimentation along the south coast of Saba. Most of the vegetated land in the footprint will be irreversibly converted to built-up or paved areas for commercial use. The remaining parts must be stabilized and revegetated, but it will take years for the vegetation to restore to pre-development stages;
- During construction of the gabions, there is a small risk of disturbance of the colony of red-billed tropicbird present at St. John's Cliffs (approximately 80-100 nests). The birds live at an

[1] The beach area at Black Rocks is a natural area, but sparsely vegetated

altitude of approximately 100-200 meters, and construction of the gabions will take place close to the 75 meters contour;

- Irreversible impacts on landscape;
- The harbor development is likely to catalyze other future developments, such as new roads and commercial developments. These are impactful by themselves, but another aspect is that worldwide, and also on Saba, seabird populations are under threat from cats and (introduced) black and brown rats, raiding nests for eggs and young. A harbor development and subsequent developments, like any development may introduce these species in the currently relatively undisturbed area. Impact mitigation has limited effect;
- In case of selection of a cofferdam type of breakwater, severe noise impacts may be expected for the colony of red-billed tropicbird at St. John's Cliffs. Adequate mitigation should be defined after quantitative noise assessment.

Marine impacts:

- Prior to the start of construction of the breakwater, all protected corals (2 species of Acropora and 2 species of Orbicella) will be relocated from the footprint area and the high-risk zone (an area where intensive work may lead to damage to corals), to an area where survival for these species is considered adequate. To assess which area is the most favorable area for relocation, a pilot project was carried out by SCF. From the trial it was concluded that 'Hole in the Corner' is the most suitable area for the relocation of the corals. The majority of the colonies of the protected corals will survive, however, a mortality of 35% which is to be anticipated in these type of projects will lead to an expected loss of 80-90 colonies (in case of a berm breakwater construction) or 50 colonies (in case of a cofferdam construction);
- Corals and other marine benthos without a protection status[1], which are estimated at several hundreds of colonies and specimens will be lost in the footprint and high-risk zone (9 ha which is in Saba's Marine Park). Impact mitigation such as enhanced settlement of juvenile corals and use of eco-friendly armor rock for the breakwater are promising, but full restoration to the pre-construction situation is not guaranteed and may take decades;
- Although more research is needed, sedimentation of nearby patch reefs is believed to be generated to a high degree by construction on land (road, weirs, harbor landside area) and to a lesser degree by marine construction[2]. Unpaved roads are one of the major contributors to sedimentation in the Caribbean, contributing 10.000x times more than vegetated areas. Impacts from land remain up to several years because several parts of the construction will not be finalized until the end of the construction period (e.g. paving of roads) and the slow process of revegetation (several years). Only by immediate action such as stabilization and revegetation of hill slopes and temporal revegetation (harbor area itself) a part of these impacts can be mitigated;
- In case of selection of a cofferdam type of breakwater, significant (possibly severe) noise impacts may be expected for marine organisms, including protected sea turtles and protected marine mammals. Adequate mitigation should be defined after a quantitative noise assessment.

Positive impacts (longer term)

Some environmental and ecological impacts from the construction of the harbour can be regarded as positive. On the longer term, the road construction has the potential to improve the current situation with respect to erosion and sedimentation, when formerly eroded slopes will be stabilized and revegetated.

[1] Such as fire coral, pillar coral, mustard hill coral, several species of brain corals, sponges, sea anemones, tube worms

[2] Research into background suspended solids concentration and deposition is needed to finalize thresholds

The presence of gabions may also have a positive impact on surrounding vegetation. The series of gabion weirs will slow down the water flow. Water will infiltrate and will become available as groundwater for longer periods.

Legal requirements

For the planned harbor construction project the following legal requirements and obligations exist:

- A ministerial decree by the Minister of Agriculture, Nature management and Fisheries is required for the relocation of 246 colonies of protected coral species (article 8a and 8b of Law on nature management BES);
- An exemption by the Scientific and Technical Advisory Committee (STAC) of the SPAW Protocol is required for the relocation of 246 colonies of protected coral species (Article 11 par. 1 and 2 of SPAW Protocol);
- An exemption by the Minister of Infrastructure and Water Management is required for the discharge of dredge spoils to open sea (article 44 and 45 of the Law on maritime management BES);
- Construction permits by OLS are needed for the breakwaters and other constructions (art. 2.2 Law VROM-BES);
- An exemption by OLS is required for the construction of the breakwater (art. 8 and art. 14 Marine environment ordinance Saba;
- An exemption by OLS is required for anchoring in waters where corals occur (art. 9 and art. 14 Marine environment ordinance Saba;
- A nuisance permit by OLS is required for development of harbour (appliances in excess of 2 horse powers);
- the Saba Conservation Foundation (SCF) may define additional conditions that need to be met before, during and after the construction activities (article 15, Marine Environment Ordinance of Saba).

Two resolutions that were adopted in the Dutch Parliament, which were put forward with respect to projects on Bonaire, may have relevance for Saba as well. These resolutions state that coral destruction must be prevented and that projects that harm corals should not be approved[1].

Conclusions

Main conclusion

The EIA demonstrates that a number of impacts can be reduced to the level “moderate” or lower. A number of impacts however remain at the level “significant”. The most important ones are:

- loss of ecological values in the terrestrial footprint, such as removal and disturbance of habitat for terrestrial species of high conservation value and habitat fragmentation;
- loss of ecological values in the marine footprint, mainly removal and disturbance of habitat for protected corals and other marine species of conservation value;
- anticipated loss of 35% of the 246 transplanted colonies of protected species (amounting to 80-90 colonies)
- disturbance of a colony of red-billed tropicbird at St. John’s Cliffs (80-100 nests) during construction of the gabion weirs
- impacts on landscape, the catalyzation of other future developments
- erosion in the project area and sedimentation of nearby patch reefs
- in case of the choice for a cofferdam breakwater, possible harm to marine organisms (including sea mammals) due to noise.

[1] Motie van de leden Van Raan en Simons over projecten die het koraal beschadigen geen doorgang laten vinden. Motie van het lid Boucke c.s. over natuurbescherming waarborgen en koraalvernietiging voorkomen

Preferred technology
From an ecological point of view, a caisson structure for the breakwater is the preferred option, because (1) it results in a smaller footprint than the base case, (2) it results in the relocation of less protected corals compared to the base case and (3) it results in significantly less noise for the colony of red-billed tropic bird (approximately 200 birds / 100 nests at St. Johns Cliffs) and for marine fauna, including sea mammals.

The cofferdam construction-method will create more noise (underwater and above water) because of a period of 4 months of intensive pile driving. If this method is preferred from a viewpoint of harbor construction, a quantitative noise assessment is needed (both terrestrial and marine), to demonstrate that disturbance will remain at acceptable levels.

Erosion and sedimentation
Erosion in the three watershed areas near the proposed and current harbor is taking extreme proportions, and is harming the marine environment in the waters south of Saba. This is already the case in the current situation. The proposed construction of a new harbor will certainly contribute to this. Therefore, impact mitigation is crucial. Slope stabilization and revegetation could have a longer-term positive impact.
Although more research is needed into background turbidity, sedimentation and current velocities in the waters of south Saba, impacts from elevated turbidity and sedimentation by marine construction and dredging are considered to be less impactful than sedimentation by terrestrial construction, which takes place on a wider scale and during a longer period.

Stakeholders views
Of five stakeholders contacted, one is opposed to the harbour project (dive operators), two have certain concerns but are not directly opposed (Saba Conservation Foundation and [redacted]) and two are in favour (fishermen, Government). Most stakeholders agree on adequate compensation for ecological impact.

Recommendations

Immediate and full execution of all proposed mitigating measures
In case of a positive decision in favor of the harbor development at Black Rocks, it is strongly recommended to immediately and fully execute all proposed mitigating measures. Especially slope stabilization and revegetation alongside the roads should start immediately after profiling of the slopes, well before road paving takes place, to reduce erosion and sedimentation. Likewise, slope stabilization and revegetation at the weirs and temporal revegetation of the harbor area should take place immediately after construction and levelling.
Uncontrolled development in the Black Rocks harbor area should be prevented to the maximum by the Saba Government.

Preferred technology for construction of breakwater
From an ecological and environmental point of view, it is recommended to construct the breakwater as a caisson structure. If the choice is made for a cofferdam structure, it is recommended to select the method of vibro-driving for the piles and to carry out a quantitative acoustic assessment (both terrestrial and marine), based on this choice. Based on this study finetuning of mitigating measures can take place (e.g. defining safety zones for marine mammals).
If the choice is made for a berm breakwater, it is recommended to use a caisson structure at the quay side of the breakwater. This will result in the use of 35% less backfill material and will considerably lower turbidity and sedimentation.

Research

In addition to the research that has already taken place (see Annex 14), it is recommended to carry out further research into background turbidity, light attenuation, sedimentation and current velocities in the waters near Black Rocks for at least 3 months. These data can help refine the chosen (preliminary) thresholds for background turbidity and sedimentation for marine construction and dredging. The marine works should comply with the final thresholds.

Compensation campaign

In case of a positive decision from the OLS in favor of the harbor development at Black Rocks, it is strongly recommended to start an extensive campaign with the purpose of compensating for ecological losses and impacts.
One option for compensation may be the island wide definition of a coastal zone where only limited development and low impact development should be allowed and where erosion control measures will be carried out (e.g. through the Saba Marine Environment Ordinance).
Another option for compensation is the complete ecological restoration and revegetation of the three heavily disturbed watershed areas in the South of Saba: the lower parts of the watershed area of Fort Bay (near the access road) and the two watershed areas west and east of Sint John's (higher and lower parts, including the stone mine). Provided that goats will be kept out of the area, reforestation and revegetation of these areas will restore the natural runoff patterns, and reduce sedimentation of Saba's south coast reefs (including Tent), which will be an important step towards to restoring these coral reefs on the longer term.

Other possible compensation measures with positive impacts are:

- Relocation of all corals and sponges, not only protected corals
- Creation of artificial reefs, in line with "Diadema City" (see chapter 9) at "Gary's Pond", which provides shelter for at least 2000 specimens of Diadema antillarum, a large quantity of fish with high fish diversity, and very good conditions for coral recruitment
- Create a fund for coral restoration projects
- Compensation of the loss of 2 dive sites by creating a spot for divers and snorkelers near the harbor, where they can work on coral (restoration or monitoring) projects;
- Adequate management of waste water all over the island
- Enforcement of BES Bouwbesluit (building regulations)

Monitoring

It is recommended that the Harbor Project Organization and The Public Entity of Saba draft and execute or order for monitoring plans for the following situations:

- Baseline survey on water quality (turbidity, light attenuation, sedimentation), currents, waves, coral reef health, and associated ecosystems during 3 months (part of Environmental Management Plan by specialized consultant/Contractor);
- Monitoring of corals impacted by construction activities (part of Environmental Management Plan by specialized consultant/Contractor);
- Monitoring of relocated corals;
- Monitoring of colony of red-billed tropicbird at St. Johns' Cliffs;
- Monitoring of quantity and quality of runoff in the new harbor area before, during and after construction;
- Monitoring of sea mammals during pile driving during 4 months (in case of cofferdam breakwater).

Monitoring results will be used for final definition of thresholds for suspended solids and sedimentation and for adaptive management (changing works when needed).

Timely submission of request for exemption at the Scientific and Technical Advisory Committee (STAC) of the SPAW Protocol

For the relocation of approximately 246 protected colonies an exemption needs to be submitted to the Scientific and Technical Advisory Committee (STAC). As STAC meetings are held infrequently, it is recommended to submit a request for exemption as soon as possible (ultimately 3 months in advance of a planned meeting).

Before submission it is recommended to:

- prepare a draft decision by the Minister of Agriculture, Nature and Food Quality, based on article 13 (paragraph 1 and 2) and article 8b of the Law on nature management BES;
- finalize the results of the pilot project for selecting the best location for relocation;
- Assess numbers of *Acropora palmata* in other sites of Saba. SCF is currently working on this.

Other recommendations

The resolutions of the Dutch Parliament with respect to impacts in coral reefs in Bonaire may present a risk for the Black Rocks project. It is recommended to further evaluate their significance and implications.

The Saba Conservation Foundation (SCF) may define additional recommendations and conditions that need to be met before, during and after the construction activities.

1 Introduction

1.1 Background

In 2018 EcoVision prepared an Environmental Impact Assessment (EIA) for the harbor reconstruction of Fort Bay Harbor by assignment of the Public Entity of Saba (OLS). This reconstruction was required following the damage caused by hurricanes Maria and Irma to the Fort Bay Harbor in September 2017. Funding was made available to repair and upgrade the existing harbor and make it hurricane and future proof. The preliminary designs were completed by the end of 2018 based on building a new secondary breakwater and an extension of the primary breakwater to provide a sheltered and safe harbor. Validation of the design was carried out early 2019 in a physical scale model (Arboleda et al, 2019) for regular and extreme (category 5) hurricane conditions.

The test results demonstrated that the hurricane wave impacts, especially for the primary breakwater, could be extremely high. The measured impact force was about 7.5 times higher than anticipated in the preliminary design. This is caused by the very steep foreshore and water depth directly in front of the Fort Bay harbor, which causes 15m high waves to break directly onto the extended breakwater structure resulting in very high impulsive wave loads. These wave forces resulted in collapse of the originally designed structure. Several measures were implemented: increase of structure width, pile diameter, pile driving depth and concrete deck thickness. With all these measures combined, the Finite Element Model calculations still showed that the structure would deform significantly and permanently, even after a single peak wave. The conclusion therefore was that it was not a hurricane proof structure.

Various alternatives were considered to reduce the impulsive wave loading, one of them being a change in structure type. Even with very large and heavy structures, it was still possible that the structures would be damaged under hurricane conditions.

It is crucial that the harbor remains operational after a hurricane, as it is, besides the small airport with very limited possibilities, the only port of entry to Saba. The model test findings fueled a discussion about the merits of investing a significant amount of money in the existing Fort Bay harbor when there would remain a substantial risk of severe damage or even collapse during hurricane events. It was concluded that the reconstruction of the Fort Bay Harbor does not result in a hurricane and future proof harbor.

A feasibility study was carried out (van der Plas, 2019) looking at an alternative location further east along the coast in the so-called Giles Quarter / Black Rocks area. This location was suggested by a number of stakeholders on Saba, as an area with a gentle topography and lower wave heights during storms.

The feasibility study indicated that at this location hurricane wave heights would indeed be significantly less due to the gentler foreshore. The shallower waters also allow construction of a harbor closer to the shore at reduced cost and risk. The topography offers substantial benefits over the Fort Bay in the sense that it is flatter and gentler and offers more space for landside (harbor) developments, both now and in the future.

From a viewpoint of harbor development, the Black Rocks area has several advantages compared to Fort Bay:

- shallow water and thus gentler wave conditions during hurricanes, greatly reducing the risk of severe damage or collapse of key harbor infrastructure
- a safer and much more sheltered harbor for the local fleet, ferries and visiting yachts
- more useable space for future harbor expansion

- availability of land for future development, which can contribute to increased economic activity
- possibility of a second access road directly to St. Johns/Windwardside, which bypasses the (dangerous) Fort Bay Road
- opportunity to develop attractive and user-friendly land-side harbor facilities in Saban style architecture, which will contribute to a better tourist experience
- land ownership is more straightforward

Disadvantages or challenges are:

- it is a greenfield project
- risks with road connection
- higher total investment

Early October 2019 formal approval was given by the steering committee, consisting of members of the Executive Council of the Public Entity Saba and representatives of the Dutch Ministry of Infrastructure and Water Management, to advance with the site investigations, design and impact assessments for the Black Rocks Harbor.

OLS asked EcoVision to produce an Environmental Impact Assessment (EIA) for the harbor at Black Rocks. This EIA is a document aimed to support the decision making for the harbor construction project. It is a legal obligation based on the Law on maritime management BES and the Saban Ordinance on the marine environment.

In this EIA, environmental impacts of the construction of a new harbor at Black Rocks are evaluated. Preferably, location alternatives are also incorporated in an EIA, especially if no other spatial instruments are available. Since the upgrading of the Fort Bay harbor cannot be regarded as a viable/feasible alternative (see first section of this paragraph), this location alternative will not be included in this EIA. The previously performed EIA for renovation of the Fort Bay harbor (EcoVision, 2019) indicated less impact on nature and environment than the development of a greenfield harbor at Black Rocks. For transparency reasons we decided to include a summary of the results of the 2019 EIA (see Annex 15).

1.2 Main features of harbor construction project

The main elements of the harbor construction project at Black Rocks (“voorgenomen activiteit”) are the following:

- the extension, renovation and paving of an existing dirt road between Fort Bay Harbor and Black Rocks, including connections to current infrastructure;
- the construction of gabions for water management, north of the projected harbor area;
- the construction of a breakwater and quays;
- dredging of the harbor to specified depth;
- construction of harbor facilities.

Possibilities for future expansion (including the possibility of a new second road) have not been conceptualized and are not included in the EIA.
Figure 1.1 shows the harbor in the new situation. In chapter 3 all project activities and project elements are described in more detail. In paragraph 1.4 and chapter 3 a number of alternatives are discussed.

1.3 Objective of the Environmental Impact Assessment

The objective of the EIA is:

- to assess the natural values in the harbor area (both marine and terrestrial);

- to assess the environmental situation in the harbor area (both marine and terrestrial);
- to assess the environmental and ecological impacts of the harbor construction project at Black Rocks;
- to define mitigation and compensation measures for these impacts.

Figure 1.1 Black Rocks current situation (top) and proposed harbor with access road and gabions for water management (north of harbor).

1.4 Scope of EIA

In a geographical sense, for the marine environment, direct impacts will be described in the footprint area of the breakwater and the harbor basin and a "high risk area", west and south of that area. Direct impacts are for instance removal of corals and impact from anchoring. Indirect impacts, such as sedimentation, will also be evaluated for the area 500 meters down current of the harbor and 300 meters up current of the harbor.
For the terrestrial environment, direct impacts will be studied in the footprint area of the proposed road (e.g. vegetation removal), the footprint of the proposed gabions, the areas to be excavated and the lay-down areas.

Important focus areas for the EIA will be:
- impacts on terrestrial nature (mainly vegetation and birds)
- impacts on marine nature (mainly corals, other benthic/sessile species, fish, marine mammals)
- protected flora and fauna species, both terrestrial and marine
- direct impacts in footprint areas by marine and terrestrial construction, or by anchoring

- indirect impacts such as
    - impacts from deteriorated water quality (turbidity and sedimentation) and impacts on coral reefs
    - impacts from noise

Environmental impacts from the activities have been evaluated in this EIA for the anticipated project (base case), i.e. the construction of a berm breakwater. In addition, impacts have been described for the following alternatives:

- construction with prefab caissons
- construction of breakwater with cofferdams

Impact assessment has been done both in qualitative ways (e.g. sedimentation from terrestrial sources) and quantitative ways (e.g. sedimentation from construction of breakwater and dredging; losses in footprint areas). Impacts are presented using a classification and ranking system as much as possible.
A baseline study for the marine environment was carried out partly by literature study and partly by a benthic survey by Saba Conservation Foundation. The survey involved seafloor characterization and counting of protected corals. The baseline situation for the terrestrial environment is largely based on literature study and field survey by SCF.

The EIA focusses on the impacts of construction and does not elaborate on impacts during the operational phase of the harbor. The main reason is that no information exists on the future use of the area (type of companies, oil/fuel storage, waste water management etc.).
The EIA does not elaborate -as discussed in paragraph 1.2- on future expansion plans of the harbor, since these plans are not known yet. However, the possibility of these developments occurring is briefly evaluated in chapter 7.

The relocation of fuel tanks of the fuel station in order to make space available for a new road connection, is already executed and is not included in the EIA. Likewise, noise impact on humans (e.g. for the population of St. Johns) is not included in the scope of this EIA.

Figure 1.2 shows the main baseline research areas. The trajectory of the road is not indicated as an area, this area was observed as a line transect.

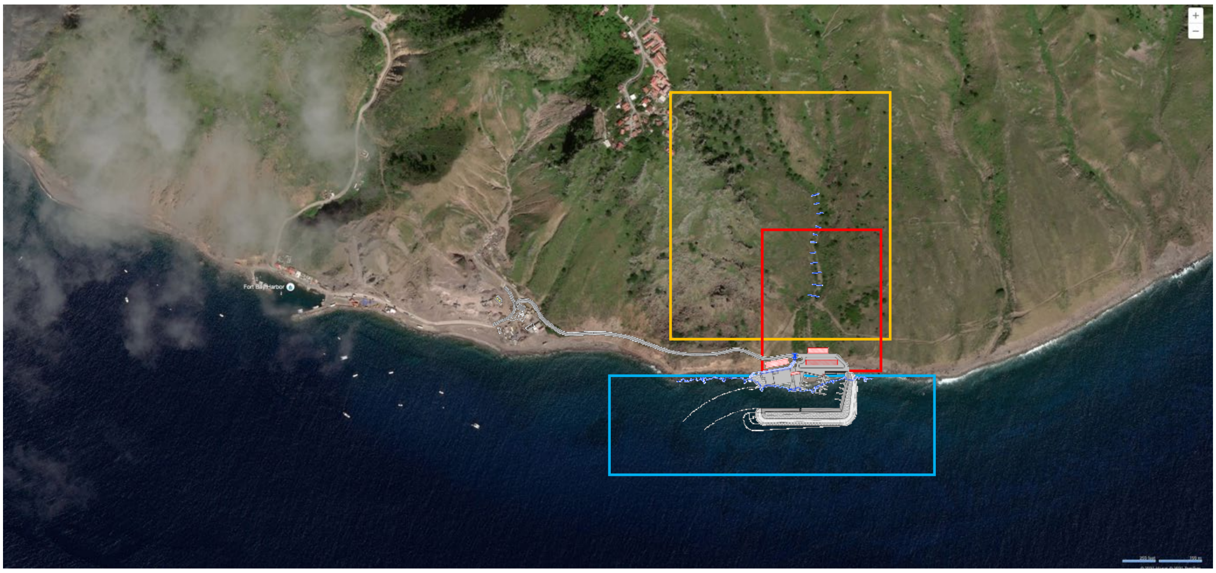

Figure 1.2: Main research areas: red (300x350m) vegetation survey; orange (650x500m) bird survey, blue (800x250m) marine survey

2 Policy, legal and administrative framework

International, national and Island legislation was surveyed in order to extract the relevant legal requirements for the development project, with respect to environment and nature. The following legislation is considered relevant.

2.1 International law

The Convention for the Protection of Migrating species (CMS) aims to protect vulnerable and endangered migrating fauna species, while the Cartagena Convention and SPAW Protocol also aim to protect regionally important areas, fauna species (Annex II of SPAW Protocol) and plant species (Annex I of SPAW Protocol). Annex I plant species do not occur on Saba (Nature Policy Plan of Dutch Caribbean 20013-2017).

Table 2.1 presents a list of important species occurring on Saba, including their specific protection status. Species protected by the CITES Convention (trade regulation) are not included in this overview.

Table 2.1: Protected species by International Conventions

Protected Species	Protection status (*)
Brown pelican, Audubon shearwater, Roseate tern	SPAW Annex II
Green turtle, Hawksbill turtle	SPAW Annex II; CMS Appendix II; Interamerican Sea Turtle Convention
Whales and dolphins	SPAW Annex II; CMS Appendix I (Humpback whale)
Whale shark and other sharks	CMS Appendix II
Corals: *Acropora palmata, A. cervicornis, Montastraea annularis* and *M. faveolata*	SPAW Annex II

* Explanation: Annex II SPAW: "total protection and recovery"
Appendix I CMS: "parties shall endeavour to strictly protect them by: prohibiting the taking of such species . . "
Appendix II CMS: parties are encouraged to "conclude global or regional Agreements for the conservation and management . . "

With respect to environmental hygiene the Marpol Convention is important for harbors. According to Annex IV of Marpol, Governments are required to ensure the provision of adequate reception facilities at ports and terminals for the reception of sewage, without causing delay to ships (source: IMO).

Relevant articles

The Saba National Marine Park is listed as Protected Area under the SPAW-Protocol and the development of the harbor will have effect on the Acropora and Montastraea species listed under Annex II of the Protocol. Article 5 par. 2 of the SPAW Protocol specifies the protective measures, which include:

Article 5 Protection measures
Paragraph 2 sub e): the prohibition of activities that result in the destruction of endangered or threatened species of fauna or flora and their parts and products, and the regulation of any other activity likely to harm or disturb such species, their habitats or associated ecosystems.

Article 11 Co-operative measures for the protection of wild flora and fauna
1. The Parties shall adopt co-operative measures to ensure the protection and recovery of endangered and threatened species of flora and fauna listed in Annexes I, II and III of the present Protocol.
a) . . . .
b) Each Party shall ensure total protection and recovery to the species of fauna listed in Annex II by prohibiting:
i) the taking, possession or killing (including, to the extent possible, the incidental taking, possession or killing) or commercial trade in such species, their eggs, parts or products;
ii) to the extent possible, the disturbance of such species, particularly during periods of breeding, incubation, estivation or migration, as well as other periods of biological stress.

2. Each Party may adopt exemptions to the prohibitions prescribed for the protection and recovery of the species listed in Annexes I and II for scientific, educational or management purposes necessary to ensure the survival of the species or to prevent significant damage to forests or crops. Such exemptions shall not jeopardize the species and shall be reported to the Organization in order for the Scientific and Technical Advisory Committee to assess the pertinence of the exemptions granted.

Article 13 Environmental impact assessment
Paragraph 1: In the planning process leading to decisions about industrial and other projects and activities that would have a negative environmental impact and significantly affect areas or species that have been afforded special protection under this Protocol, each Party shall evaluate and take into consideration the possible direct and indirect impacts, including cumulative impacts, of the projects and activities being contemplated.

Significance for project

The construction process for a new harbor will lead to "taking, possession or killing" of Annex II (coral) species, within the scope of Article 11 of the SPAW Protocol. Parties to the Convention are instructed to prohibit this. Exemption from this prohibition is possible on only three grounds: 1) for scientific purposes, for education and awareness-raising purposes and 3) for management purposes (conservation of species).
Harbor construction is not covered by any of these exceptions. SPAW has no exemption option for economic purposes and refuses to recognize these. In the case of transplantation of Annex II species, however, it can be argued that this is for the survival of the species.
Article 13 states the requirement of an Environmental Impact Assessment (EIA), which has to be sent with the request for exemption.

2.2 National laws

2.2.1 Law on Maritime management BES

With the Law on Maritime Management BES (Wet maritime beheer BES) a number of international conventions are being implemented in national legislation, among others The United Nations Convention on the Law of the Sea, the Cartagena Convention (and SPAW Protocol), the OPRC Convention and the Marpol Convention. The ordinance aims to regulate activities taking place in the sea (territorial sea and EEZ) in such a manner that the marine environment, natural values, archeological values and maritime safety are being managed in a sustainable way. Examples of regulated activities are: construction of piers and breakwaters, buoys and beaches, installation of cables and pipelines, discharge of objects and substances, and certain ship related activities causing nuisance (e.g. smoke) and danger.
The competent authority for the implementation of this law is the Dutch Minister of Infrastructure and Water Management. By Decree of the Minister, parts of the competences can be delegated to the Executive Council of Saba.

Relevant articles

Relevant articles and paragraphs in the Law on Maritime Management BES are (in Dutch):

Artikel 20

1. *Het is verboden zonder of in afwijking van een vergunning van de beheerder, bouwwerken te hebben, aan te leggen of te doen aanleggen in of op de bodem van de territoriale zee of de exclusieve economische zone.*
2. *Het eerste lid is van overeenkomstige toepassing op landaanwinning en op werkzaamheden die een verandering van het niveau of van de gesteldheid van de zeebodem tot gevolg hebben.*

Artikel 21

1. *Bij de beoordeling van de aanvraag voor een vergunning als bedoeld in artikel 20, eerste lid, worden de effecten van de aanleg en het gebruik van het voorgenomen bouwwerk op het mariene milieu, de natuur, de veiligheid van de scheepvaart en het maritiem archeologisch erfgoed uitdrukkelijk in overweging genomen.*
   . . . .
6. *Aan een vergunning kunnen voorschriften en beperkingen worden verbonden in het belang van de veiligheid van de scheepvaart en de bescherming van het mariene milieu, de natuur en het maritiem archeologisch erfgoed.*

Artikel 44

1. *Het is verboden zich vanuit schepen of bouwwerken, in de territoriale zee of in de exclusieve economische zone:*
   a. te ontdoen van afval of andere stoffen, dan wel deze te verbranden; of . . .

Artikel 45

1. *Onze Minister kan voor één of meer stoffen, genoemd in Bijlage 1 van het Protocol van 1996, ontheffing verlenen van het verbod genoemd in artikel 44, eerste lid.*

Significance for the project

For marine construction works, such as the planned harbor construction, a permit from the Dutch Minister of Infrastructure and Water Management is required (article 20.1).
The discharge of dredge spoils to the open sea (if needed), would require an exemption from the Minister of I&W. This possibility exists for dredging spoils (Annex 1 of the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972).
Article 21.1 stipulates that effects of the construction works and the impacts of the structures on the marine environment, marine nature, navigational safety and maritime archaeology need to be assessed and evaluated.

2.2.2 Law “VROM-BES” and implementing decrees

The Wet (Law) VROM-BES (BWBR0031218) regulates a number of topics:

- Construction (chapter 2)
- Public Housing (chapter 3)
- Waste and waste water (chapter 4)
- Environmental Permits (chapter 5)
- Soil quality (chapter 6)
- Environmental Impact Assessment (chapter 7)
- Emergency situations (chapter 8)
- Substances (chapter 9)

For waste and wastewater, only few articles have been enacted. These are mainly focused on collection of waste and wastewater and on policy formulation.
The chapters on environmental permits and Environmental Impact Assessment are largely complete, however, so far no lists are present of activities that require a permit or EIA. Therefore other Laws and Ordinances must be adhered to with respect to permits and EIA.

Chapter 6 (Soil) and chapter 9 (Substances) have not yet been enacted.

With respect to/regarding soil quality on Saba, the Dutch Law on environmental management (Wet milieubeheer), the Decree on soil quality (Besluit bodemkwaliteit) and the Regulations on soil quality (Regeling bodemkwaliteit) are not valid. This also means that the normative framework for re-use of soil and dredged materials is not valid on Saba, but, on the other hand, may be adopted as a guideline.

In the implementing decree "Bouwbesluit BES" (BWBR0036000) the requirements for applications for construction permits are stipulated.

Relevant articles

Relevant articles and paragraphs in the VROM-BES law are:

Artikel 2.2
1a. Het is verboden te bouwen zonder of in afwijking van een door het bestuurscollege verleende bouwvergunning

The relevant authority for the regulation is the Saba Executive Council ('Bestuurscollege').

Significance for the project

Construction permits are needed for the breakwaters and constructions on land[1].
The normative framework for re-use of soil and dredged materials is not valid on Saba, but may be adopted as a guideline ("Besluit bodemkwaliteit" and "Regeling bodemkwaliteit").

2.2.3 Law on Nature Management BES

The Law on Nature Management (Wet grondslagen natuurbeheer BES) is the national instrument for implementing international conventions on nature management into national and local legislation. The most important topics in this law are:

- the formulation of nature policies
- protection of areas
- protection of species

Articles from the law that are of importance to the project are summarized below.

Artikel 8a lid 2
Het is verboden handelingen of activiteiten te verrichten als bedoeld in artikel 11, eerste lid, onderdeel b, van het SPAW-protocol, ter zake van diersoorten, opgenomen in Bijlage II van dat protocol, en eieren, delen of producten van deze diersoorten.

Artikel 8b
Bij ministeriële regeling kunnen ten aanzien van de verboden, bedoeld in artikel 11, eerste lid, van het SPAW protocol, vrijstellingen worden verleend als bedoeld in artikel 11, tweede lid, en artikel 14 van dat protocol, nadat de Wetenschappelijke en Technische Raadgevende Commissie in evengenoemd artikel 11, tweede lid, de gegrondheid van de te verlenen vrijstellingen positief heeft beoordeeld.

Artikel 10
1. *De eilandsraad stelt, voor zover mogelijk, natuurparken in.*
2. *Op natuurparken als bedoeld in het Verdrag van Ramsar, het SPAW-protocol of het Biodiversiteitsverdrag, zijn de hieraan in deze verdragen gestelde eisen van toepassing.*

[1] We interpret that a road is not a construction as meant in the Law VROM-BES and that for road construction a construction permit is not required.

3. *De eilandsraad die een zodanig natuurpark heeft ingesteld, geeft hiervan kennis aan Onze Minister met vermelding van de ter zake relevante informatie.*
4. *Onze Minister draagt de gemelde natuurparken voor bij het desbetreffende uitvoerende bureau dat bij deze verdragen is ingesteld, met het verzoek tot opname in de bij dat verdrag horende lijst van beschermde gebieden.*

Artikel 11
De eilandsraad draagt zorg voor de beheersmaatregelen voor en de bescherming van soorten die vermeld zijn in de bijlagen van het Zeeschildpaddenverdrag.

Artikel 12
De eilandsraad draagt zorg voor de bescherming van en de beheersmaatregelen voor soorten die vermeld zijn in de bijlagen van de Bonn-conventie.

Through this BES legislation, the species included in Annex II of the Protocol, are also under a national protection regime. A number of sea mammals, bird species, sea turtle species and coral species are listed in Annex II of the SPAW Protocol (see paragraph 2.1). For these species the national and Island governments are required to ensure "total protection and recovery"[1].
Exemptions from this rule are possible under conditions, i.e. after a positive advice from the Scientific and Technical Advisory Committee (STAC) of the SPAW Protocol. According to the authorities, the STAC is usually informed afterwards.

Significance for the project

The Saba National Marine Park is listed as Protected Area under the SPAW-Protocol (see for implications paragraph 2.1).
During the preparation phase and the execution of the project, negative impacts for the following species must be minimized with high priority:

- The sea turtle species that live in Saba's waters: the Green turtle and the Hawksbill turtle;
- All species of whales and dolphins that live in Saba's waters;
- Whale shark and other sharks;
- The Brown Pelican, Audubon shearwater and the Roseate tern;
- Four coral species: *Acropora palmata, Acropora cervicornis, Montastraea annularis* and *Montastraea faveolata.*

A policy guideline of RCN is that if only small numbers of protected coral colonies need to be removed (and can be relocated), an exemption from the Minister of Infrastructure is not needed. In case of larger numbers, this exemption, as well as the advice from STAC is required.

2.2.4 National Ordinance on spatial planning BES, 2010

According to this ordinance, a zoning plan can be developed, based on a number of policy objectives (article 3), as well as on a Development Program by the Dutch Minister of VROM (if present) and an Island Ordinance that further defines the procedures for a zoning plan. Such an ordinance has not yet been enacted on Saba. A zoning plan (or partial zoning plan) is not present, nor in preparation.

Significance for project

The project cannot be reviewed against a zoning plan since such a plan has not yet been developed.

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[1] SPAW Protocol article 11 clause 1 sub b: *Each Party shall ensure total protection and recovery to the species of fauna listed in Annex II by prohibiting: i) the taking, possession or killing (including, to the extent possible, the incidental taking, possession or killing) or commercial trade in such species, their eggs, parts or products ii) to the extent possible, the disturbance of such species, particularly during periods of breeding, incubation, estivation or migration, as well as other periods of biological stress.*

2.3 Island Ordinances

2.3.1 The Marine Environment Ordinance of Saba

The Marine Environment Ordinance of Saba (1987) was established with the aim of setting regulations for managing the marine environment of the Island of Saba, in order to preserve the natural resources of that environment for commercial as well as educational, recreational and scientific purposes. The scope of the Ordinance is the area of the Saba Marine Park, which is defined as the marine area between the coastline (high-water mark) and the 60 meters isobath. Figure 2.1 presents the contours and use zones of the Saba Marine Park (source: Saba Conservation Foundation).

Four management zones currently exist within the Saba Marine Park.

1. a mooring zone
2. a multi-purpose zone
3. a no-take zone, and
4. a recreational zone

Figure 2.1 illustrates the locations of these zones. The harbor project is located in a "multi purpose zone". The use regulations are partly defined in the Ordinance itself, partly in the Island Decree on Marine Management of June 25, 1987 (A.B. Saba 1987, no. 11)[1] and partly in the Saba Marine Park Management plan (1999). The competent Authority for the execution of the Ordinance is the Executive Council of the Public Entity of Saba.
Table 2.2 shows the regulations for the relevant zone.

Table 2.2: Use regulations for zones near harbor

Zone	Allowed	Not allowed
multi-purpose zone	Fishing, limited diving (*)	Anchoring in areas with coral growth (article 9 of Ordinance)

(*) According to Saba Marine Park Management Plan

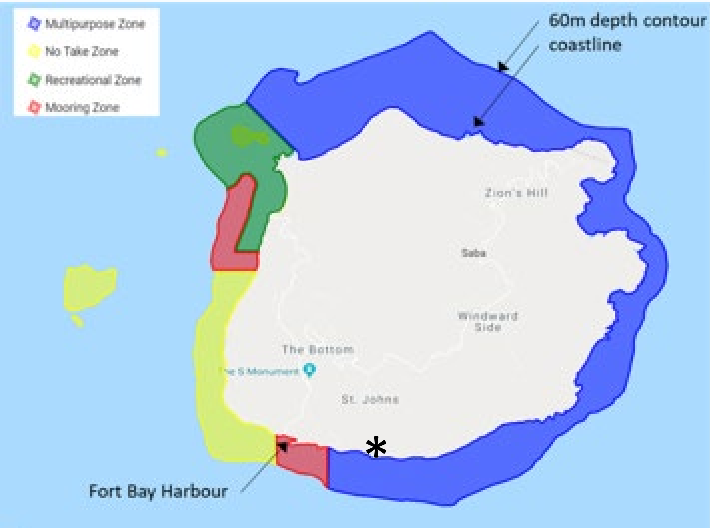


Figure 2.1 Saba Marine Park and the various zones (source: http://www.sabapark.org/marine_park/zoning_system/
(location Black Rocks marked by asterisk)

Below, a number of relevant articles from the Ordinance are summarized.

[1] Island Decree on Marine Management of June 25, 1987 (A.B. Saba 1987, no. 11)

Artikel 2

Het is verboden enige handeling te verrichten welke in strijd is met de bepalingen van het zoneringsplan voor het Saba Marine Park, zoals vastgesteld bij eilandsbesluit houdende algemene maatregelen.

Artikel 8

1. *Het is verboden in het Saba Marine Park handelingen te verrichten die schadelijk zijn voor het mariene milieu.*
2. *Het is verboden opzettelijk het marien milieu in het Saba Marine Park te vernielen.*
3. *Het is verboden koralen en andere op of in de bodem levende evertebraten en planten te doden, af te breken, te vangen of te verzamelen.*

Artikel 9

1. *Het is verboden in het Saba Marine Park te ankeren op met koraal begroeide bodem.*

Artikel 11

Het is verboden enige stof te lozen in, of uitvloeiend naar het Saba Marine Park, met uitzondering van vis of visafval, visvoer, koelwater van schepen en spoelwater van onderwatertoiletten van schepen.

Artikel 12

Ontwikkelingen of veranderingen van de kustzone welke het marien milieu van het Saba Marien Park kunnen beïnvloeden dienen voorafgegaan te worden door een onafhankelijk milieu-effect rapportage.

Artikel 14

5. *Het Bestuurscollege kan voor wetenschappelijke of educatieve doeleinden ontheffing verlenen van een of meer verbodsbepalingen van deze verordening.*
6. *Het Bestuurscollege kan, in bepaalde gevallen, voor commerciële doeleinden ontheffing verlenen van de verbodsbepaling van artikel 8, derde lid.*
7. *Aan de ontheffing kunnen voorwaarden worden verbonden. Alvorens ontheffing wordt verleend wint het Bestuurscollege deskundig advies in.*

Artikel 15

Gebruikers van het Saba Marine Park zijn verplicht de aanwijzingen van de personen welke belast zijn met het beheer van het Saba Marine Park stipt te volgen.

Significance for the project

Activities which are harmful to the marine environment are not permitted in the Saba Marine Park (article 8.1). Harbor developments will most likely qualify as such activities, however, article 14.1 stipulates that exemptions for these activities can be granted for commercial purposes[1].
If working barges need to drop their anchors, this may only be done in areas without coral cover (article 9.1).
The harbor development project must be preceded by an independent environmental impact assessment (article 12).
The Saba Conservation Foundation (SCF) may define additional conditions that need to be met before, during and after the construction activities (article 15).

2.3.2 Nuisance Ordinance for the Windward Islands and implementing decrees

The Nuisance Ordinance for the Windward Islands (A.B. 1966, no. 4) regulates the establishment and modifications of facilities that potentially cause nuisance, damage or safety risks for the (people in the) environment. The main article of the Ordinance is article 1:

[1] The English version of the Ordinance states in Article 14.1: *The Executive Committee may grant exemptions from one or more of the prohibitions in this Ordinance for scientific **or commercial** or educational purposes*.

Artikel 1
1. Het is verboden inrichtingen, welke gevaar, schade of hinder kunnen veroorzaken, op te richten zonder vergunning, welke, behoudens de bij of krachtens deze eilandsverordening gemaakte uitzonderingen, door het Bestuurscollege wordt gegeven.
2. De in het vorige lid bedoelde inrichtingen worden bij eilandsbesluit, houdende algemene maatregelen, aangewezen.

The implementing decree (Hinderbesluit) features a list of activities that need to be permitted according to the ordinance. A harbor construction or extension is not a listed activity as such, but can be classified under “facility with electromotors with a rated power of 2 HP and more”.

Significance for project

A harbor can be regarded as a facility in which electromotors with a rated power of 2 HP and more will be used. Therefore, a request for a Nuisance permit should be addressed to the Executive Council.
Likewise, for the relocation of the tanks for gasoline and diesel (not included in this EIA), a Nuisance permit will be required.

3 Project description (base case)

3.1 General description of project

The Black Rocks harbor construction project aims at providing a harbor well protected against hurricane waves. It includes the construction of a breakwater and dredging/excavation works to provide a new harbor basin including berthing facilities. The harbor requires a road connection, for which an old dirt road needs to be renovated and paved.

With respect to materials, the project aims to re-use excavated materials as much as possible and to result in a neutral mass balance, i.e. no materials need to be landfilled or deposited elsewhere. Nonetheless, the option of depositing sediments in open sea in a way that is compliant to Dutch standards (see chapter 4), is still open.

A series of drawings included in annex 1 demonstrates an overall construction sequence as is envisaged for the project. The final phasing, sequencing and methods may vary depending on the final solution as is chosen by the Contractors. The realization of the harbor is divided in three main phases:

- Phase 1 – enabling works, including the construction of the road, utilities, drainage/run-off control structures, levelling of terrain and the relocation of protected corals offshore
- Phase 2 – the construction of the harbor including the main breakwater, quay walls, finger piers and harbor terrain surfacing and utilities
- Phase 3 – the construction of harbor buildings

The project scope includes phases 1 and 2. Phase 3 will be realized in the future and requires a separate design, permitting and construction process. This document provides more detail with each of the (sub)phases.

3.2 Enabling works - construction phases

Phase 1.1 and 1.3 Construction of road

The existing dirt road between the existing road network at the fuel station (west) towards the Giles Quarter area is rehabilitated and upgraded to a two-way road. This includes the following works:

- Levelling and widening in places of the entire road (approx. 800m length along the final route from existing road to the east side of the new harbor terrain), including road base compaction. The width of the construction road is approximately 7-8m.
- Benching and slope stabilization in a section of about 250m in the western part, including a revetment along the shore to protect the lowest section of the road against erosion by waves and run-off. The minimum elevation of the road is around +10m MSL (above Mean Sea Level).
- Creation of a temporary connection to the existing road along the shore (west side), until the existing fuel tanks along the final route have been relocated.

The road surface during construction phase consists of a typical sub-base material (e.g. 0/30mm) which is compacted. This is easy to maintain and level while being used by heavy construction traffic. After completion of the main construction activities (in approximately 18-24 months), the final road surfacing will be installed (concrete). The completion of the excavation works and compaction of the road is expected in Q3 2022.

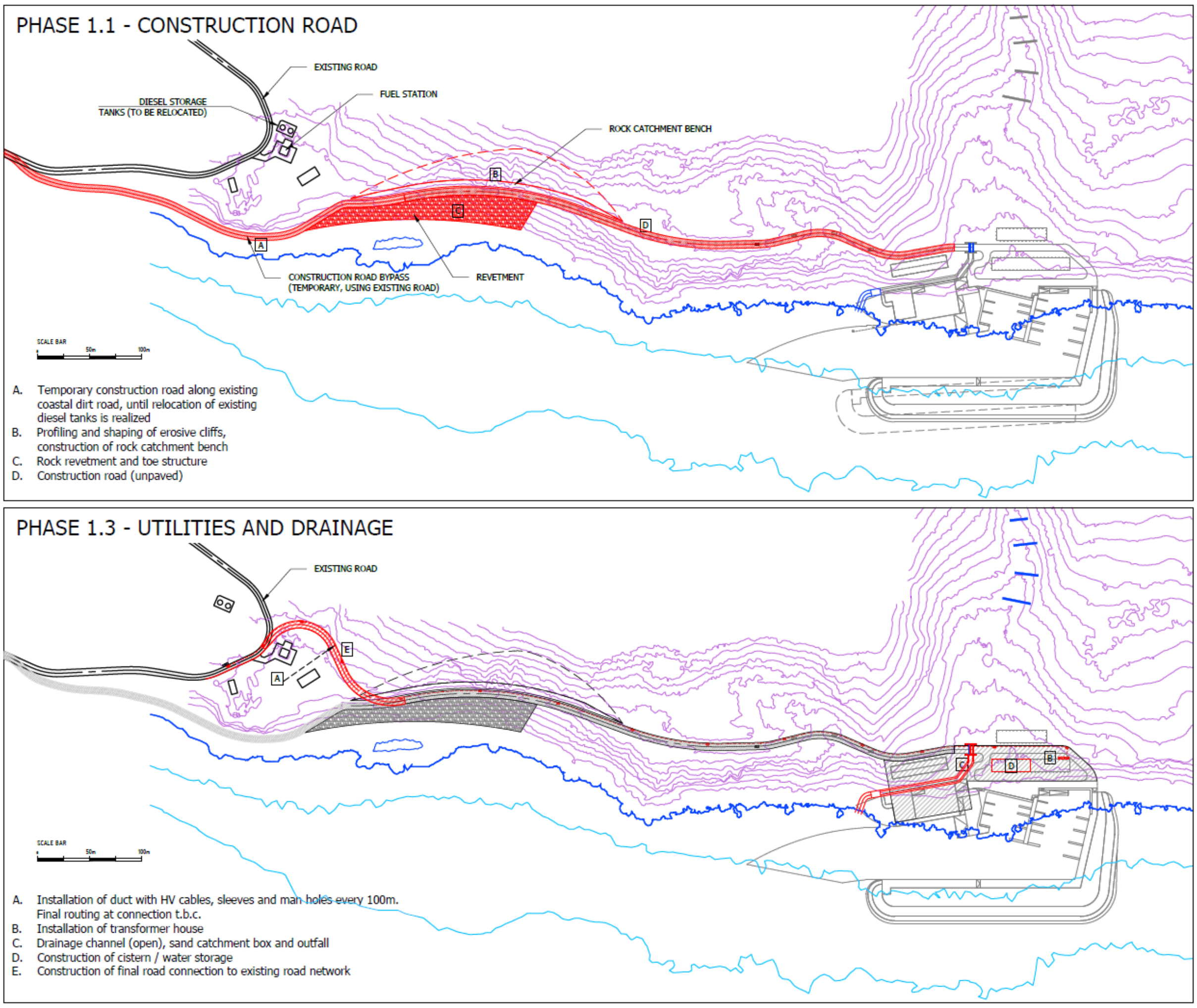


Figure 3.1: Two phases of road construction. Top: connection to harbor area by means of temporary road along the coast (currently unpaved road). Bottom: final road connection after relocation of fuel tanks.

Phase 1.2 Laydown area, drainage structures, coral relocation

After completion of the construction road, the future harbor terrain is made accessible, by cutting, filling and levelling the various areas to their approximate final elevations. These areas will also serve as construction site and laydown area for the main marine works contract. The total area is approximately 11,000m2 including the future roads on the harbor terrain.

A series of small gabion weirs is constructed above the future harbor area to control and direct the flow of water from the hills. For these weirs 'gabions' will be used as building blocks. Gabions are steel wire baskets filled with stones. The use of gabion weirs has less impact on the environment compared to earth or concrete dams[1], because of:

- A smaller footprint
- Less earthworks/excavation
- Use of local materials
- Use of manual labor and/or small machines
- Blend more easily into the landscape

The eleven gabion weirs will be positioned in the gut north of the harbor, see Figure 3.2. The eleven weirs will be placed between the 30m and 75m contour. Depending effectiveness during periods of

[1] Food and Agriculture Organization of the United Nations. 2001. Small dams and weirs in earth and gabion materials, Rome, Italy.

intense rainfall, an additional seven weirs may be required downstream. The weirs have a length of 10-30m and a height of 2m relative to the lowest point in the gut. The weirs have a stepped shape, see section in Figure 3.2.

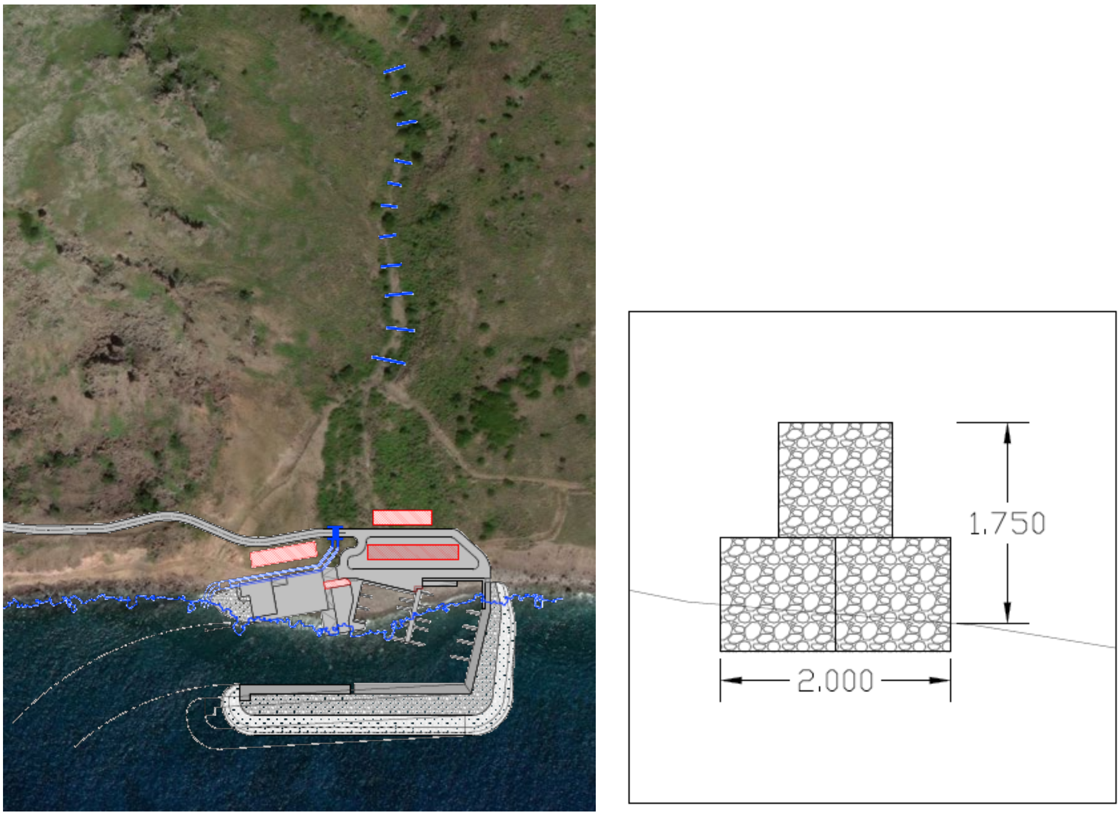


Figure 3.2: Positioning and design gabion weirs

In this phase the existing transformer station near the fuel station will be upgraded to serve as a suitable connection point for the new HV power lines to the new harbor area. This work is most likely carried out by SEC or a SEC sub-contractor.
The existing (2) fuel tanks north of the fuel station will be relocated by Big Rock Engineering (BRE) to another location on the BRE terrain, in order to provide room for the final connection between the new road and the existing road.

To mitigate the negative impact of the new harbor structures on the local (protected) coral colonies, a coral relocation program will be carried out prior to start of the marine works contract. This includes removal of all colonies of protected coral species to another, yet to be defined, location outside the project zone. This relocation is most likely carried out by (or with assistance from) SCF, using divers and simple tools (hammer, chisel, etc).
The estimated duration of the works in this phase is approximately 3-6 months.

Phase 1.3 Utilities and drainage

A trench will be excavated on the side of the construction road, with manholes at regular intervals (75-100m) with steel covers. The trench will contain HV cables as well as plastic sleeves for future fiber optic cables and other services as required. The duct is approx. 0.5m wide x 0.5m deep and will be backfilled. A transformer house will be erected at the harbor location, to convert from HV to LV power. This transformer house is about 9m x 2m and will be integrated in the future buildings on the harbor terrain.

The main drainage channel and outfall is created on the west side of the future harbor area. This is an open channel, lined with smaller rocks on the side. At the crossing with the future road, concrete box culverts will be made.

At the location of one of the future harbor buildings, a large cistern will be constructed. This includes excavation, base compaction and casting of a concrete box with roof. The final dimensions are yet to be defined.

After relocation of the diesel tanks, the final road connection can be realized, linking the harbor road to the existing road directly west of the fuel station. The temporary construction road along the shore remains operational for the duration of the project serving as a back-up route, also for heavy traffic.
The estimated duration of these works is approximately 3-6 months. Part of the works can be executed simultaneously with phase 1.2.

3.3 Breakwater layout and design alternatives

At this stage, the final orientation and length of the main breakwater is not decided yet but depends on the final go-ahead for an improved design to make the harbor suitable for future, larger (90m LOA), RoRo vessels. The base-case layout (breakwater with 180m length) and the improved layout (breakwater 210m length) are shown below[1]. In this EIA we assume the realization of the larger structure for all environmental impacts. The width of the breakwater depends on the construction method chosen (with the rubble mound breakwater being the widest with 40 meters).

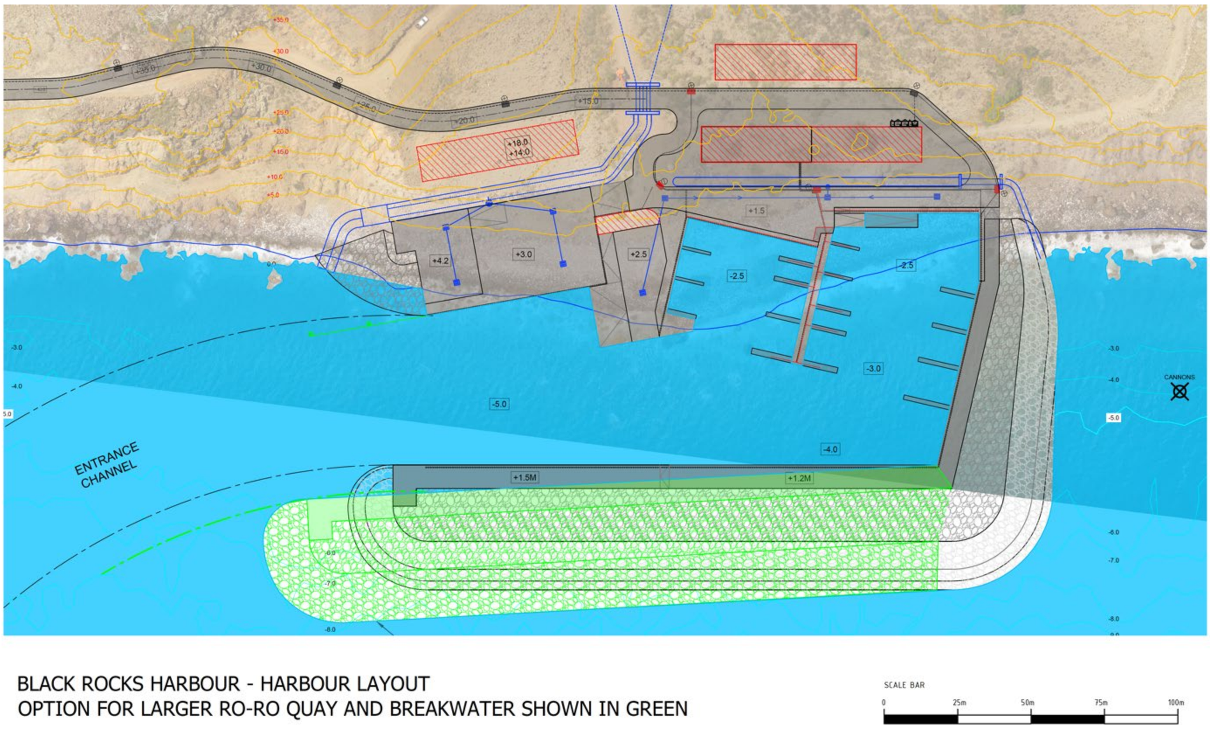


Figure 3.3: Footprint of rubble mound breakwater (180m length: grey contour, and 210m length: green contour)

The construction method of the breakwater and quay wall depends on the final design and installation method chosen by the contractor. The following typical designs are possible (to be validated in physical modelling):

1. a cofferdam breakwater as was used in the design for Fort Bay
2. a caisson breakwater
3. a rubble mound breakwater

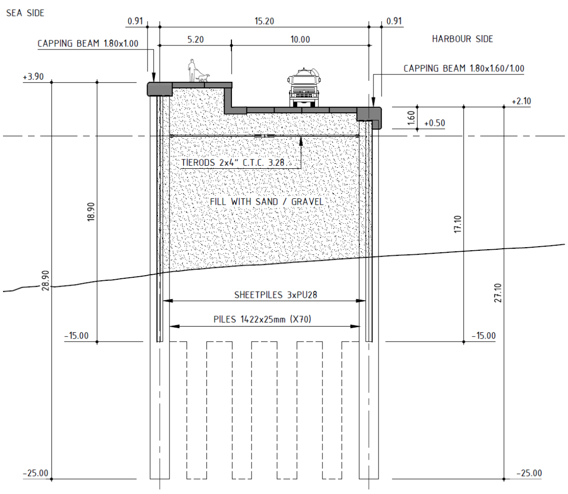
[1] At the final stage of the EIA process the final design was available, but it was decided to leave it like described in this EIA report as a worst-case scenario.

The principle solutions are presented below. It is noted that the design has not been finalized yet, so final dimensions may still vary. At the same time, it is expected that in terms of overall dimensions, footprint and construction methods, the description below is robust and provides a realistic input for the assessment of possible environmental impacts.

Cofferdam breakwater

A cofferdam breakwater/quay consists of two ‘combi-walls’ placed about 10-15m apart (width depending on final design), connected with tie rods and backfilled with suitable material. A combi wall is a combination of main piles at regular intervals (e.g. 2-3m center to centre) and thinner sheetpiles in between. A principle section and picture are shown in Figure 3.4.
The construction of the cofferdam starts with clearance of the seafloor and removal of large rocks and boulders.
Two parallel rows of main piles with diameter of about 1-1.5m are driven into the substrate by means of a diesel hammer, a hydraulic hammer or a vibration head (installed on an excavator). Between the piles, sheet piles are driven into the substrate (3m below seafloor), also by means of a hammer or a vibrating mechanism. The installation depth of the main piles depends on the final design but is likely in the order of 10m. The number of piles depends on the final selected pile dimensions and centre-to-centre distance. For the Fort Bay reference design a centre-to-centre distance of 3.2m was used. For the Black Rocks harbor this results in about 170 piles (length of breakwater 180m) to 190 piles (length of breakwater 210m).

Pile driving takes place with a mobile crane working progressively from the newly constructed parts of the breakwater. In deeper water a barge may be needed for the crane. In those cases the barge can anchor at the newly constructed piles, to reduce anchoring on the seafloor.
If rocky substrates are encountered beneath this level, these could be broken first by means of a heavy steel H-profile driven into the substrate, or drilled out, or removed by other means (grab, etc). The resulting two separate combi-walls are connected by tie rods (horizontal steel rods as shown in the figure below and backfilled with suitable rock/gravel/sand material. A concrete beam is cast on top of the main piles to provide a solid coping for the quay (on the harbor side) and a hard edge for the pavement.



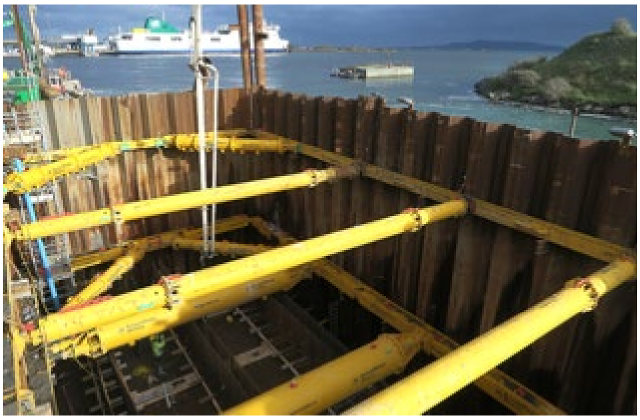


Figure 3.4: Example of typical cofferdam structure (schematic, left) and under construction (right)

A minimal scour protection may be installed at the seaward side of the cofferdam, depending on the final proposed design and results of the physical modelling, but is not expected. If needed, this scour protection will likely consist of one or two layers of armor rock and can be installed by means of an excavator working from the land side, or from a barge.

Based on a work progress of 2 piles per day, pile driving (piles and sheet piles) will take a maximum of 4 months[1].

Caisson breakwater

An alternative for the main breakwater and quay structure is a caisson. Figure 3.5 shows an example of a typical deep-see caisson (left) and a modular caisson (right). The caisson structure is a suitable alternative in waters of medium depth[2].

Figure 3.5: Example of typical caisson structure (left) and modular caisson (right)

A reference design has been made yet for the caisson breakwater, see Figure 3.6.

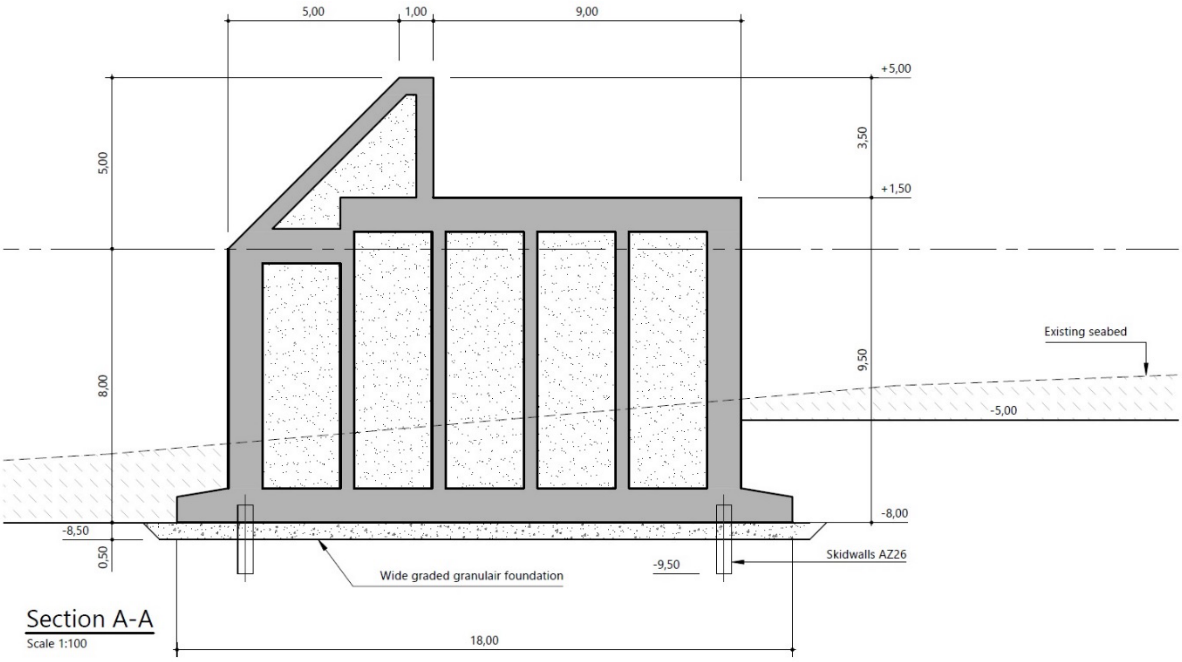


Figure 3.6: Reference design for a caisson breakwater).

Before the placement of the caissons on the seafloor, the seafloor needs to be prepared (levelled). This includes removal of rocks currently present on the seafloor. This work will be executed with a barge and an excavator. A second step in the levelling of the seafloor is the application of a 30-50 cm layer of foundation material, which typically is crushed granular material.

[1] Based on 2 piles per day, 12 hr/day and 5 days/week

[2] In the situation of Fort Bay, the caisson structure was not suitable for the primary breakwater because of the excessive width that would be required to withstand the hurricane wave impacts

The caissons may be constructed in a dry dock (floating or fixed), on land adjacent to a slipway, or on a special pontoon which sinks as construction progresses. Given the limited space on Saba, it is considered to construct the caissons off-island, and transport these to Saba. This transportation can either be done by floating the caissons and towing these to Saba with tug boats, or by using special transport vessels like semi-submersible vessels. Examples of caisson transportation are shown in Figure 3.7 below.

Figure 3.7: Example of caisson transportation by tugs (left; this is a 1970 picture of the construction of the Fort Bay main breakwater), and by semi-submersible vessel (right).

As soon as the seafloor has been prepared, the caisson elements can be placed on the seafloor one by one. This process will be executed by ballasting the caissons so that they sink onto the foundation bed. Typically, this ballasting is done with seawater, which after placement of the caisson is replaced by ballast material (sand/stone). The positioning of the caissons will be aided by tugs and/or anchor pontoons. This will involve anchoring in the area.

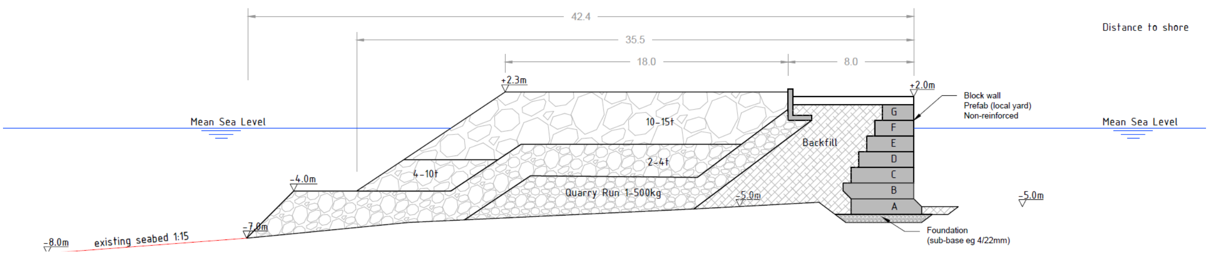
Although the caissons may be constructed off-island, some concrete work may still be done on the island. This may include (part of) the concrete deck and the wave wall on top of the structure. This can be constructed as prefab elements, cast in the construction laydown area and placed on the caissons, or cast in-situ on top of the caissons using formwork.

Aggregates for the concrete can be imported or obtained from the local quarry adjacent to the harbor. Fresh water is available from the RO plant in the harbor. Cement and reinforcement steel will be imported. The concrete will be mixed in concrete mixers / concrete batching facility present on the laydown area.

Rubble-mound breakwater (berm breakwater)

Another alternative is a rubble mound breakwater. Typically this consists of a rock core and filter layers, covered with armour rock or concrete units. Considering the severity of the wave climate in Saba, large concrete units (>30t per unit) would be required if a traditional (steep slope) rubble mound breakwater is designed. Given the specific challenges associated with the production, transport and placement of these large units, this design is not considered feasible.

As an alternative, a so-called ‘berm breakwater’ is designed. The cross section (yet to be validated in physical scale model testing) is shown below.



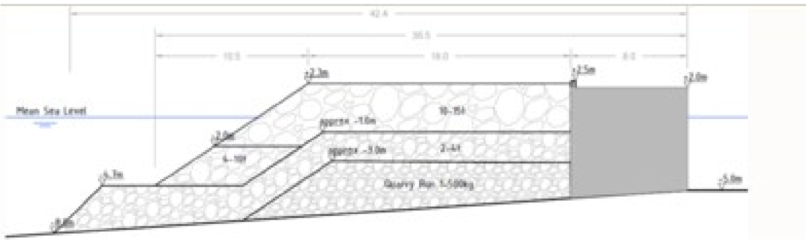


Figure 3.8: Top: section view of berm breakwater (base case). Design with block-wall at quay side (A-G)
Bottom: technical option with caisson at quay side (no backfilling of quay)

The berm breakwater design is based on creating a wider breakwater (approximately 40m wide, see figure 3.8), but with smaller rocks on the outside. During a storm some movement and reshaping of the rocks is allowed, according to the principle below.

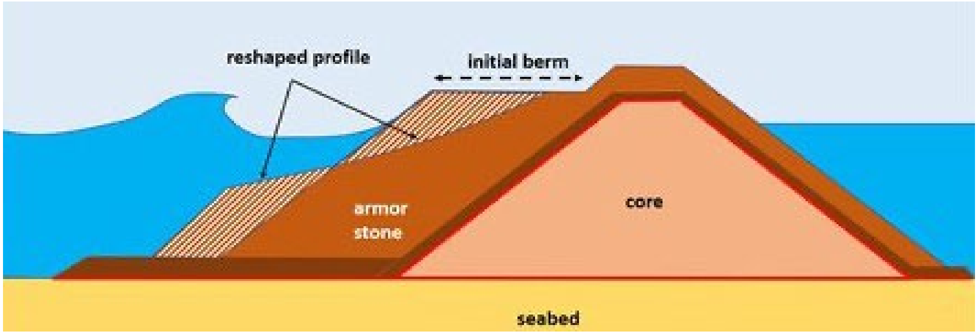


Figure 3.9: Movement and reshaping of berm breakwater

The construction can be built with a combination of land-based and marine-based equipment. The final method depends on various factors such as the location of the rock supply (by land or by sea), considerations around workability in offshore conditions, placement tolerances, etc. Typically, the core is constructed from the shore using trucks back-tipping the cargo at the end of the bund. The subsequent layers can be placed by excavators working from the crest, or by crane for the larger rocks at longer distances.

A marine-based construction is also possible using flat top barges from where the rock will be pushed in the sea, or more advanced floating equipment such as side stone dumpers or split barges. A marine-based construction is also more logical in case the rock is supplied by sea. In that way, double (or triple) handling of rocks is prevented.

The vertical quay wall on the landside is a separate construction activity. The planned construction phasing is based on first creating a breakwater structure to provide shelter, so that the quay wall can be constructed in calm sea conditions. The quay wall itself can be constructed with concrete blocks, or alternatively by a caisson structure, or a piled anchored wall (see previous descriptions). In case of a block wall, the concrete blocks are cast on site (land) and transported over the partially completed breakwater to the working front. A crane is used to lift and place the blocks in the final position.

3.4 Marine construction works - construction phases

Phase 2.1 Site set-up, start main breakwater

After award and mobilization of the marine works contractor, a start will be made with the set-up of site offices, construction yards and laydown areas.

The first main activity will be the start of the main breakwater and quay wall (see annex 1). The construction method of the breakwater depends on the final design and the selected construction equipment by the Contractor. Reference is made to the previous paragraph.

Phase 2.2 Main breakwater, quay wall east

When the breakwater has advanced sufficiently, a start can be made with the land-side construction of the quay walls. The partially completed breakwater provides shelter against waves so that the land-side construction activities are less dependent on the wave climate.
The landside quay wall is a relatively low retaining structure, with a landside of about +1.5m MSL and a depth of about -2.5m (east basin) to -3.0m MSL (west basin). A typical cross section, based on a concrete L-wall, is shown below.

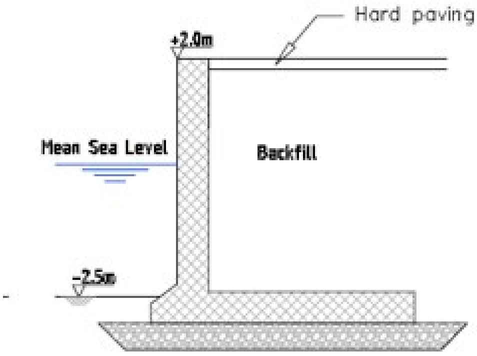


Figure 3.10: L-shaped wall (top level should be +1.5m)

The location of the landside quay walls makes it possible to consider a dry, land-based, construction method. In this method, a small protection dike is constructed on the seaside, above seawater level, after which the construction pit is excavated and dewatered. The method prevents any exchange of sediments and seawater. After levelling, the foundation layer (gravel) can be placed. The structure type depends on the final selected solution but can be in the form of a L-shaped wall. This wall can be cast in-situ. After hardening, suitable back fill (sand/gravel) is placed and compacted in layers. The general sequencing is shown below.

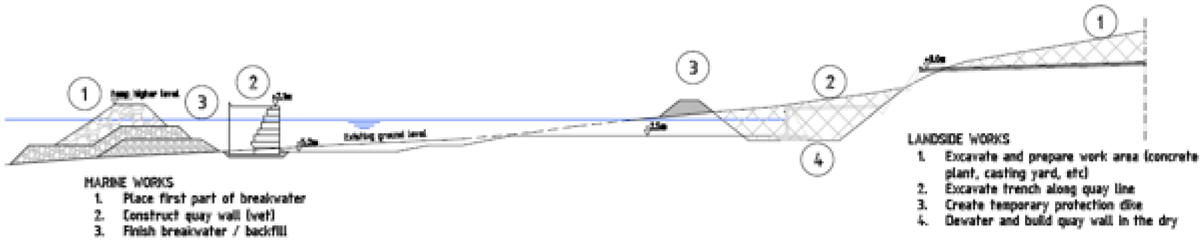


Figure 3.11: Sequence of works (marine works and landside works)

The total length of the east basin quay wall is about 50-60m (length depending on the exact transition to the main quay wall on the east or the central pier on the west). The quay wall includes a boat ramp structure.

Phase 2.3 Main breakwater, main quay wall, central pier

With the advancement of the main breakwater and quay wall, a larger sheltered area is created, allowing the land-based construction activities to shift further west. The methods and sequencing are similar to phase 2.2.
The central pier is a 45m long, 4m wide structure. This can be realized as a caisson structure, as a piled structure with deck, or also as a cofferdam.

Phase 2.4 Main breakwater and quay wall, quay wall west, dredging

When the breakwater has advanced sufficiently, it starts to provide full shelter for the governing wave direction which is south-east to south-south-east. At this point, dredging may commence in the east basin (this can also be delayed unto later phases).

Dredging will be done partially from land, using “backhoe” or long boom excavators. The excavator can create its own dry construction platform into deeper water (approximately -3m MSL), working its way back to the shore. The material is then transported to land and used in the core of the berm breakwater, as ballast material in the caissons, or as infill for the cofferdam. Material is also required for the reclamation of the RoRo quay. Alternatively dredging can be performed with marine equipment, using a barge with excavator. This is likely the selected method for the deeper parts of the harbor basin. Sediments from the harbor will be re-used and placed securely in the reclamation area. If these materials cannot be used in the project (e.g. because of excess material in the mass balance) this material may be deposited in the open sea.

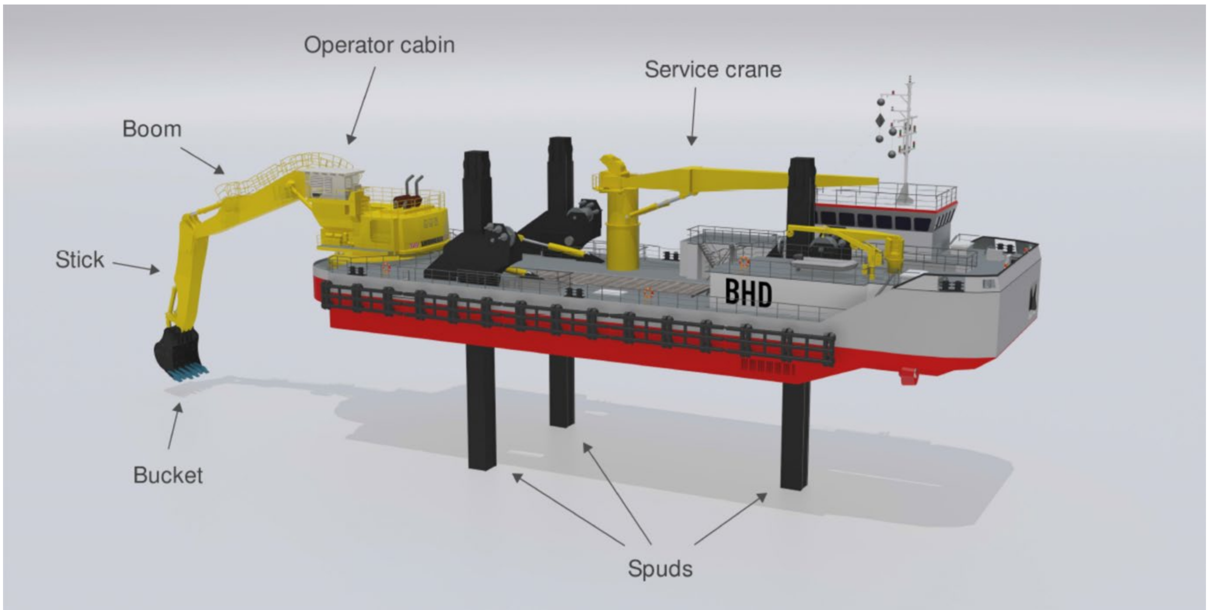


Figure 3.12 Example of barge with excavator

In this phase also, the west basin quay wall is constructed. Perpendicular to the quay wall, finger piers are to be installed. These finger piers are currently planned as piled structures, with a robust (concrete) deck on top. A few finger piers will be fitted with boat lifts (see picture below).
The total length of the west basin quay wall is about 90m, consisting of the north wall, west wall and the wingwalls.


Figure 3.13: Example of a boat lift and fixed jetty structure.

Phase 2.5 Main breakwater and quay wall, dredging

In this phase, a start is made with the RoRo quay. This is a vertical retaining structure of about 8m height, from about +2.5m MSL to -6m MSL. The structure type is not defined yet, but it will likely consist of one of the following solutions:

- a combi wall similar to the cofferdam breakwater, but then with a single wall, tied back with soil anchors. The piling can be done from land by first creating a dry working platform and driving the main piles and intermediate sheetpiles with a land-based crane or from sea by working from a barge. The combi wall prevents any exchange of backfill material and seawater;
- a concrete structure in the form of an L-shaped wall, or block wall, similar to the descriptions given before.

The total length of the RoRo quay wall is about 120m, including the ramp and the wingwalls on either side. A reinforced concrete coping beam is placed on top of the piles (in case of a combi-wall structure). In case the quay has to be made suitable for larger (90m) RoRo vessels, a number (2-3) of additional mooring piles is placed to the west of the quay, in the same berthing line as the main quay.

Phase 2.6 Completion main quay wall, dredging, RoRo revetment

In this phase, probably after dredging this part of the basin, the finger piers on the central pier and main quay are installed.
The main quay wall is completed, allowing the completion of the main breakwater head in the next phase (backfilling and tie-in).
The harbor area and reclamation directly adjacent to the RoRo quay have a total surface area of about 2,200m2. At the west side of the RoRo quay, a revetment is constructed to retain the reclaimed land and to provide a stable shore protection. The material for the reclamation originates from the land excavation and from dredged material from the harbor basin. Most of the material is coarse sand and gravel, although a part may contains finer material. A suitable filter will be installed between the reclamation material and the outer armor. This filter may be a wide graded granular filter (‘quarry run’) or alternatively a geotextile. A principle cross section is shown below.

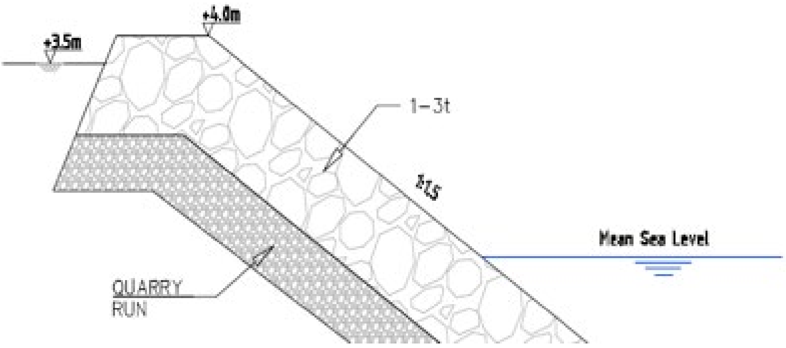


Figure 3.14: Principle cross section RoRo area revetment (geotextile between quarry run and armor rock).

Phase 2.7 Completion main breakwater, dredging, finger piers

In this phase the main marine works are completed. The final activities are the completion of the breakwater head and dredging of the entrance channel. This dredging is done by marine equipment, as described before. Where large rock boulders are present on the sea bed, e.g. in the entrance (approach) channel, these have to be reduced in size. Suitable methods are hammering or the use of expanding grout.

Phase 2.8 Utilities, drainage, boat lifts, quay furniture, pedestals

After completion of the main marine works, the so-called 'marina' elements can be installed. In total some 35 slips will be provided in the new harbor. This excludes the ferry dock, the mega-yacht berths, and the smaller boat/dinghy dock in the north-east basin. See picture below.

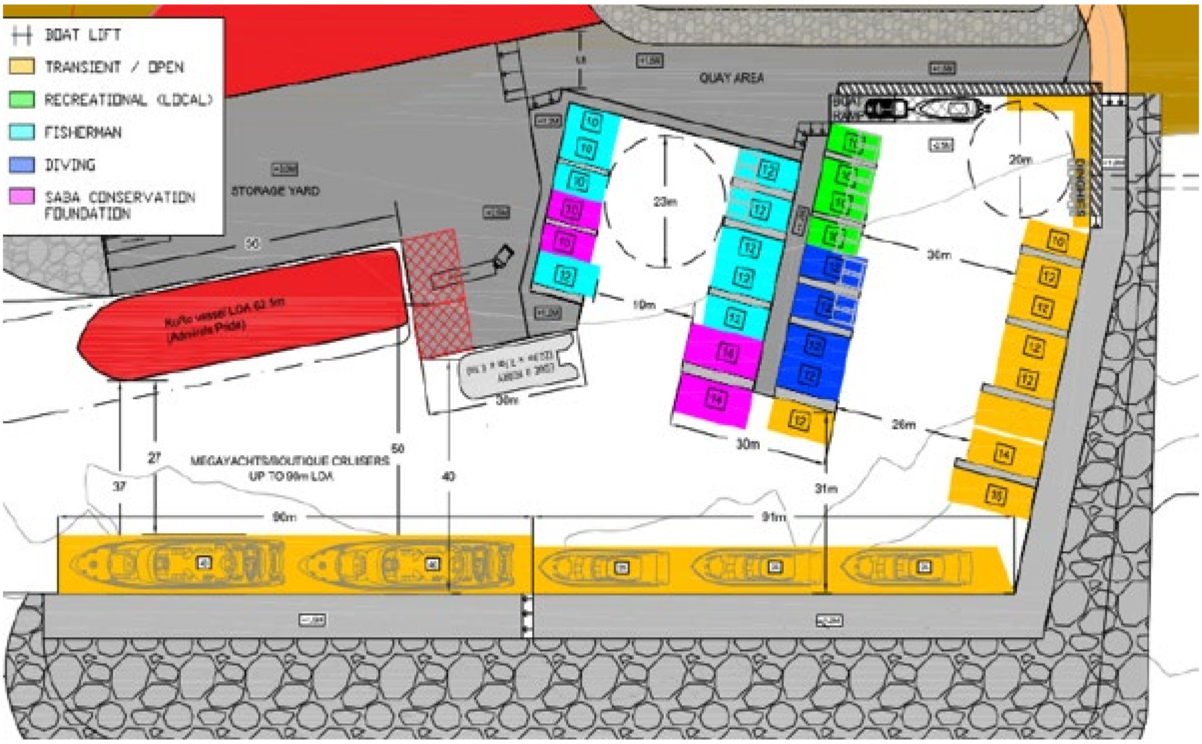


Figure 3.15 Harbor user groups

All the slips will be serviced with water and electricity. These utilities will be placed in pre-installed ducts in the quay structures and are accessible for the harbor users via pedestals. An example of a mega yacht power pedestal is shown below.

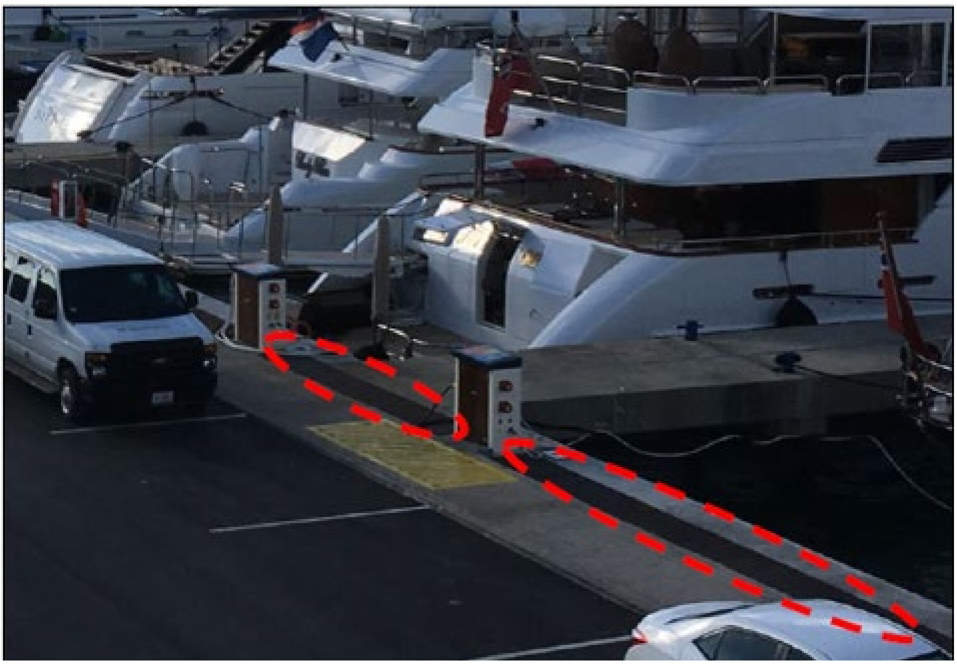


Figure 3.16: Pre-installed ducts and pedestals for water and electricity

The main quay and finger piers also require bollards and cleats at regular intervals. Fendering may be required in places (to be designed).

A fuel dock is planned at the ferry dock. The fuel system includes two times two flexi-tanks (20ft tankcontainers, with diesel and gasoline), and a double wall piping system with safety sensors, dispensers and control valves. The system does not require pumps as it is gravity-based.

The main drainage system installed during the enabling works phase, is complemented with local harbor terrain drainage. These drainage pipes run underground and discharge into the main drainage channel via an oil separator and a sand catchment box.

3.5 Finalization works, pavement, final road, lighting and fencing

The harbor area pavement is still to be designed but will likely consist of in-situ cast concrete slabs, as is customary on Saba. The gradient is away from the quay to ensure that rain water drains towards the drainage system collectors and is not discharged over the quay into the harbor basin.

The final road pavement is installed. This will be done with cast in-situ concrete with light reinforcement.

General harbor lighting is installed as well as road lighting. A fence is erected around the harbor area, complying with ISPS guidelines.

3.6 Key figures and overall planning

The completed harbor provides about 600m linear meter of dockage. This includes about 180m of side-tie along the deep part of the main breakwater (210m in case of the 30m extension), 22 dedicated wet slips, 8 boat lifts and about 60m of flexible side-tie at the proposed RoRo berthing. This offers space for at least 35 boats of various sizes.
The depths along the main quay is approximately 5m, reducing inward. The depth in the east basin is 2.5m and 3.0m in the west basin.
The total land-side harbor area is approximately 11,500m2 including the area for future harbor-related buildings.
The construction quantities largely depend on the final chosen solutions and are therefore difficult to provide at this moment. The berm breakwater would require approximately 90,000 Mt of rock armour, and approximately 17,500m^3 of core material. The total dredging quantity is between 25,000-30,000m^3.
The maximum total duration of dredging is 3 months: 2 months for the eastern basin, 1 month for the western basin and the shallow parts of the shipping lane.

The general project planning is as following:

- enabling works: total duration 6-9 months
- marine works: total duration: 18-24 months
- marina works and finalization: 3-6 months

4 Baseline situation

4.1 Hydrological and environmental situation

Hydrological situation

Figure 4.1 shows the watershed area in which the proposed harbor is located, east of St. Johns. The area is 55 ha large. Two gutters join near the center of the watershed area and from there the main gutter runs southward.
During a design storm of 180 mm per hour (with a return time of 10 years), peak runoff is 17m3/sec (storm water entering the sea through the main gutter, CCM Engineering, 2020)[1]. During a design storm of 100 mm per hour, the peak runoff is 9,4 m3/sec.
The proposed location of the harbor is exactly where the main gutter enters the sea.
The watershed west of St. Johns, approximately 50 ha large, drains to sea near the gas station.

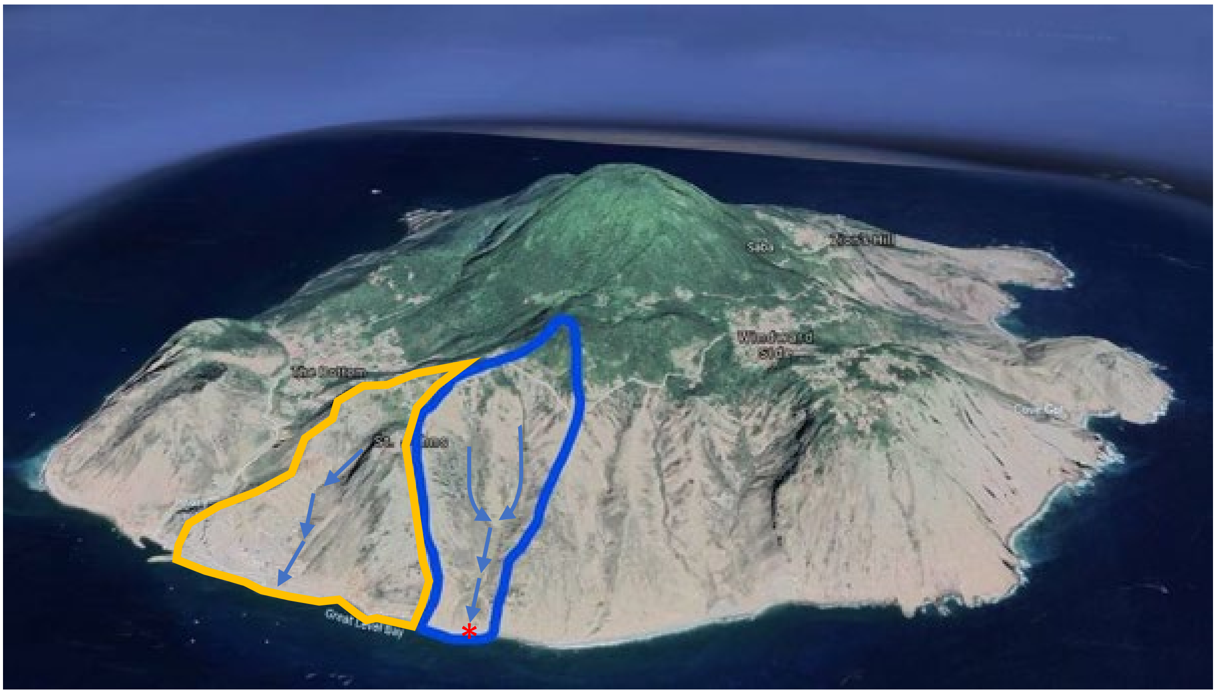


Figure 4.1: Two main watershed areas with approximate locations of main gutters (adapted from CCM Engineering, 2020 and Carmabi, 2014). Asterisk: location of proposed harbor

Erodibility

Erodibility in the watershed area is extreme to very extreme, which is probably related to the presence of high densities of goats and high intensity of goat grazing in the south part of the island (Mulder, 2017; Rojer 1997). This situation has led to large areas that remain permanently deforestated (Romeijn, 1987). In the watershed area east of Fort Bay (yellow in figure 4.1), both the higher parts and the lower parts are subject to heavy erosion (see erosion channels in figure 4.2). In the lower parts, a maze of unpaved roads and the aggregate quarry are the main contributors.

Especially unpaved roads promote extreme erosion, which is estimated to be 10.000x times higher than in natural, vegetated areas (Ramos-Scharron et al, 2006). Several landslides have occurred

[1] This design rain shower is also used for a storm drainage study for the New Fire Fighting Building project at the Saba Airport in 2018

south of St. John's, just north of the current unpaved road to Black Rocks, leaving a very unstable and erodible top layer. The present extreme situation with respect to erosion requires urgent action.

The watershed area of Black Rocks, is relatively intact, except for some distinct erosion channels in the higher parts of the watershed area. Discharge of storm water to sea is through a small "delta" (see figure 4.2, bottom left), where discharge velocities are significantly lower and where sediments deposit.

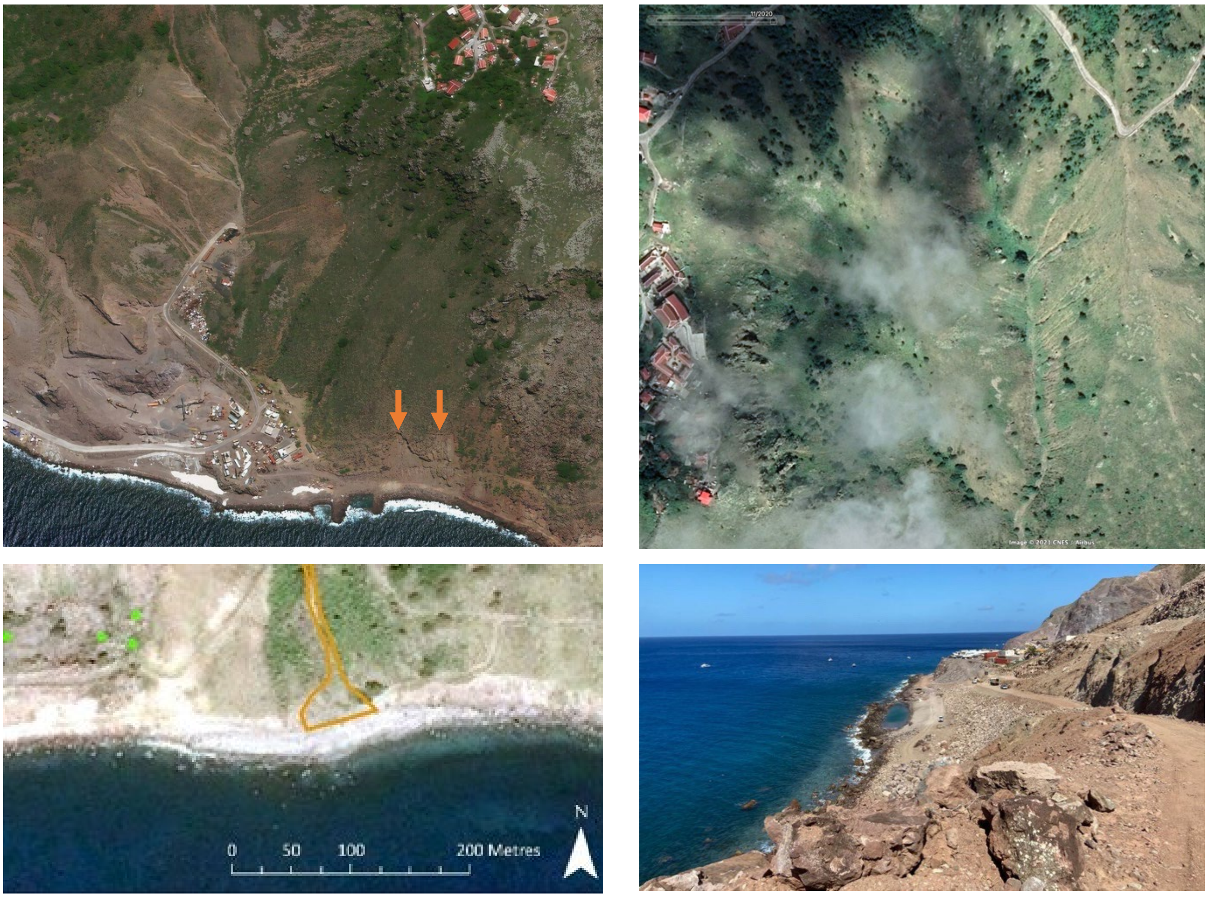


Figure 4.2: Top left: Erosion channels in watershed] west of St. John's. Arrows: landslides north of unpaved road. Top right: Erosion channels in watersheds east of St. John's. Bottom left: Trajectory of south part of gutter, with small delta near sea. Bottom right: location of proposed access road (foreground) and temporary road (background, north of Gary's Pond), which are unpaved roads at present.

Chemical analysis sediments

In November 2020 sediments were sampled by Geotron at the seafloor and on land (see figure 4.3). Samples were sent to the Dutch laboratory EuroFins Analytico for chemical analysis. Samples for chemical analysis were named as follows:

1. waterbodem 1 (mixed sand from seabed surface)
2. mix B11 + B15 (mix sample of B11 and B15)
3. surface land (mix sample from land surface samples)

Samples 1 and 2 were analyzed for contaminants, according to the C3 suite of Rijkswaterstaat (Netherlands): metals, petroleum hydrocarbons, organic chlorinated pesticides, polychlorinated biphenyls (PCB's), polycyclic aromatic hydrocarbons (PAH's) and tributyltin (TBT).
Sample 3 was analyzed for contaminants, according to the A suite: metals, petroleum hydrocarbons, polychlorinated biphenyls (PCB's) and polycyclic aromatic hydrocarbons (PAH's).

Annex 3b includes an overview of all samples taken and analyses carried out (including physical parameters).

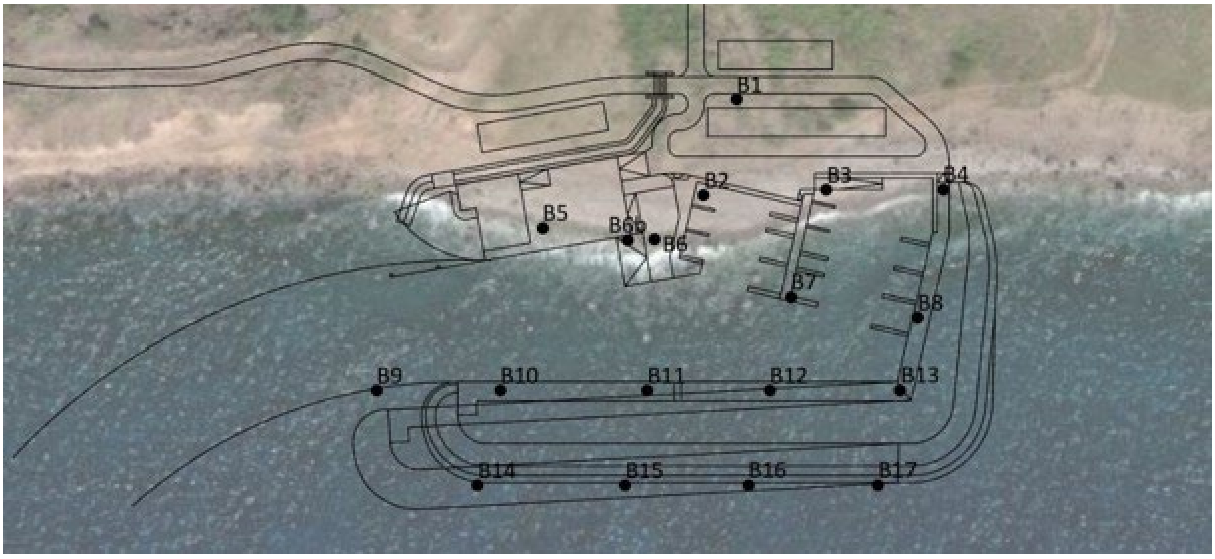


Figure 4.3 Sample locations

The pollutants in the sediments were determined to be all below the background values with the exception of nickel in the 'waterbodem 1' sample. The value of nickel was slightly above the background value. The elevated nickel concentrations are most likely naturally occurring and not exceed any intervention values for development that would require further investigation.

The results of the analyses are included in annex 4. The compliance check against the Dutch Soil quality regulations is included in same annex (BoToVa). It can be concluded that - according to Dutch policy - the dredged material can be applied in Class A environments and is allowed to be dispersed in surface waters ("T3" check)[1].
It should be recognized that the BoToVa check is developed for use in Dutch waters (e.g., the North Sea) and soils. The context on Saba is quite different and the local soil characteristics differ significantly from the Netherlands. The use of the Dutch regulations and BoToVa is not mandatory in the BES islands, but the compliance check may form a starting point for the permitting of application of dredged materials.

In 6 boreholes (nrs. BH7, BH8, BH9, BH11+15 and BH16), samples were taken for analysis on organic matter. In three of the samples organic matter was below detection limit, 0,4%), in BH9 it was 0,6% and in BH16 it was 1,6%. Organic matter content is an important factor in determining the risks of sediment dispersion for the coral reef (see chapter 6).

Physical characteristics

During the course of 2020, samples have been taken from the seafloor in the Black Rocks area for physical analysis (densities, particle size distribution etc.). See figure 4.3 for locations (B1-17) and annex 3b for a list of parameters analyzed.

The specific gravity of the gravelly sand, with locally shell fragments, equals on average 2.76 Mg/m3. Figure 4.4 shows the results from particle size distribution (PSD) as well as the average PSD based on all results, except the two outliers shown in the graph (far left and far right). The fines content (silt + clay, defined as material <63 µm) equals 4%, sand 91% and gravel 4% on average (Geotron 2020, annex 4).

[1] BoToVa T3: Beoordeling kwaliteit van baggerspecie en ontvangende bodem of oever bij toepassen in een oppervlaktewaterlichaam

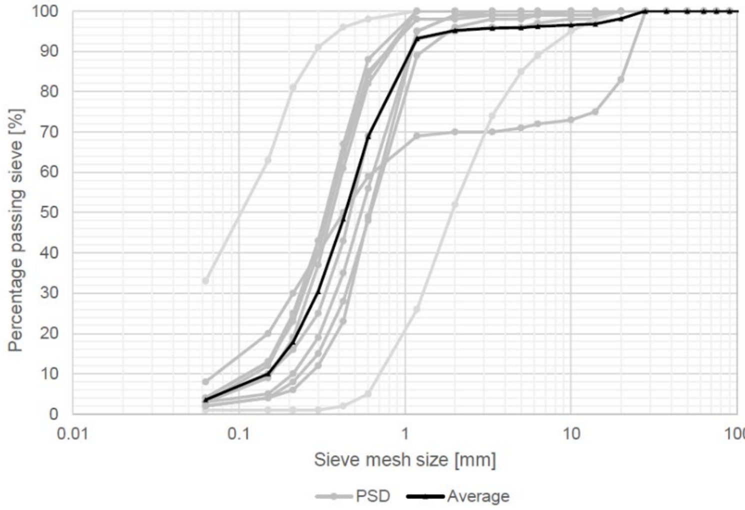


Figure 4.4 Summary of PSD results (black line indicating average values)

Water quality

For Saba no historical data with respect to water quality are available. Of special interest are background values for total suspended solids (TSS), affecting light penetration in seawater. From literature it is known that mean sedimentation (deposition) rates and suspended sediment concentrations (TSS) for reefs not subject to stresses from human activities are < 1 - 10 mg cm^{-2} d^{-1} (deposition) and < 10 mg l^{-1} (TSS) respectively. Chronic rates and concentrations above these values are considered 'high' (Rogers, 1990).
According to Hildebrand (2017) mean visibility in water (using the Secchi disk) over 20 dive sites was 27.5 meter ± 8 SD[1], which is relatively high compared to other Caribbean sites (Jackson et al, 2012). In the southern parts of Saba, where grazing by goats is intense, erosion is common and runoff will contain relatively high loads of sediments and organic material (Meesters et al., 2019; Mulder 2017).

In the period from August – November 2021, current and turbidity measurements have been carried out at the project site, at a depth of approximately 8m. The detailed results of the measurements are included in Annex 14. With regard to the water quality, the TSS has been determined, based on a generic correlation between FTU and TSS. The average suspended solids concentration is **25mg/l**, with a variation (99%) between 0 – 80mg/l.

Details are included in Annex 14. It is expected that the sea conditions during the survey are representative for typical year-round tide, currents and waves (with the exception of storms). Because these conditions are the main drivers for the turbulence levels and the TSS, it is also expected that the measured TSS values are representative for typical year-round values. Nevertheless, it is recommended to validate the measurements by additional current and turbidity measurements for a duration of at least 3 months.

4.2 Prevailing currents, wave heights

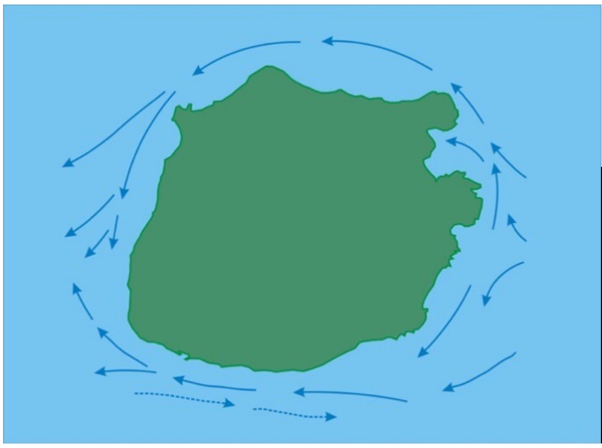
Prevailing currents are from east to west (see figure 4.5). The table in the figure presents an analysis of the data from the US Navy Hycom database[2] with respect to direction of currents as percentage of total time. These are data from the closest modelling point near Saba, 2 km east of Saba (17.6N; 62.2W).

[1] lowest visibility was 12 meters whereas the highest was 42 meters; 50% of visibility measurements was between 24 and 31 meters

[2] HYbrid Coordinate Ocean Model (HYCOM) is an initiative by the National Ocean Partnership Program (NOPP), as a part of the U. S. Global Ocean Data Assimilation Experiment (GODAE)

The data show that during 92% of the time there is a western[1] component in the current (to the west). In 8% of the time there is an eastern component in the current (i.e. to the east, reversed). Closer study of the data reveals that current reversals occur 10-20 times per year (from west to east). The longest uninterrupted period of current reversal during 2018 was 48 hours (2 days), most reversals last 3-12 hours (see annex 5).

At the nearest data point of the HYCOM database, the average current velocity is 0.24 m/s (surface layer), and velocities are below 0.4 m/s 93% of the time. With the prevailing currents from east to west, seawater moves away from the island in the area just north of Tent Reef (see figure 4.5).



Category (degrees)		Percentage of time
0-45		5
45-90		1
90-135		1
135-180		1
180-225		2
225-270		9
270-315		38
315-360		43

Figure 4.5: Current patterns around the island of Saba. Dashed line in picture left side: current reversal (information from US Navy Hycom model, and Dr. J. Rahn, Geographer). Right: Direction of currents as percentage of time (nearest point of Hycom database, 3000m SE of Saba)

No historical data is available on current velocities near the coast of Saba (pers. Comm. Harbor Master). For that reason, the HYCOM database has been used as input for the current and TSS modelling (see paragraph 6.7). The conversion from deep water current velocities to the location close to the shore has been done based on analogy with other Caribbean islands, resulting in an average velocity of 11 cm/s, with a typical range of 6 – 17 cm/s used for sensitivity assessments. The extreme range used in the modelling is 0.2m/s eastward current and 0.4m/s westward current. See Annex 11.

Recently, data has become available from the local current and turbidity measurements carried out in the period from August – November 2021. Details are included in Annex 14, a summary is given below:

- Typical figures:
  - The depth-average current during the measurement period is 0.13 m/s.
  - The maximum eastward current measured during this period is 0.3 m/s
  - The maximum westward current measured during this period is 0.45 m/s
- Currents are driven by tide and wind with the following distribution across the water column:
  - Surface: approx. 90% of time currents are westward (towards 210 – 330^0), with 90% of time < 0.3m/s
  - Mid-depth: approx 60% of time currents are westward (210-330^0), with 90% of time less than 0.15m/s
  - Bed level: approx. 50% of time currents are westward (210-330^0), with 90% of time less than 0.1m/s.

The measured average current velocity and extreme range is very similar to the model assumptions. The dominant current is westward, with about 10% of time a reversal to the east. This is similar to

[1] Contrary to wind, the direction of currents is described in terms where they are heading, e.g. a western current is heading to the west.

the HYCOM model (see figure and table above). At mid-dept and bottom, the wind driven component is less strong, and eastward currents occur more often, although at lower velocities.

Wave heights

The class of wave heights occurring most often at Black Rocks is the class of 0.5-1.0 meters[1]. During the months of August through October, waves at open sea (and therefore also at Black Rocks) are usually significantly lower, see annex 6, from Hycom database).

4.3 Terrestrial ecological values

4.3.1 Summary of literature

Vegetation

In the Landscape ecological vegetation map of Saba (De Freitas et al., 2016) the site is recorded as Aristida-Bothriochloa Mountains. This landscape type occurs on the lowest slopes of Saba in a relatively extensive and sun-exposed zone that extends from Parish to the area between Windward Side and The Level and then north to Flat Point. The Aristida - Mitracarpus type (type 9) with 4 to 27 species (10 on average) is the main vegetation type within the Aristida-Bothriochloa Mountains. This vegetation type has the lowest cover and lowest number of species. The other vegetation types within the Aristida-Bothriochloa Mountains are Bothriochloa - Pertusa (type 8) with 6 to 26 species (13 on average) and Wedelia - Plumbago (type 7) with 17 to 37 species (30 on average).
(Stoffers, 1956) recorded the site as Dry Evergreen Formations and Hippomane Woodland. In some places, especially in the deeper guts, a mixture of several species occurs, forming a dense bush of no particular structure. In Compagnie's Gut, the main gut in the proposed project area, the vegetation consists of a shrub layer about 1 m high. *Lantana camara, L. involucrata, Croton flavens, Wedelia jacquinii* and *Mitracarpus polycladus* are the predominant species (Stoffers, 1956). Total cover of the vegetation in and near these gutters range from 75% to 100%. For more information on the main species occurring in the Dry Evergreen Formations of southern Saba, we refer to annex 2a.

The southern coastal areas are being overgrazed by free-roaming goats; highest livestock densities have been observed in these areas. Also soil conditions can be regarded as poor. Vegetation in these areas could recover with the exclusion of goats, providing a natural barrier to erosion (De Freitas et al., 2016).
Invasive insects have wiped out almost all local white cedar (*Tabebuia heterophylla*) and Opuntia cacti along the coast, with the area to the south of St. Johns being identified as an important site for these species (De Freitas et al., 2016). For these reasons, the conservation status of the dry forests has been evaluated as “very unfavourable” (DCNA, 2019).

Birds

The Saba coastline has been identified as an Important Bird Area (IBA). At the south side of Saba, this area stretches 400 meters landward (Geelhoed, 2013). The IBA was defined on the basis of nine “trigger” bird species (see table 4.1). It is however for the breeding seabirds, the red-billed tropicbird (*Phaethon aethereus*) and Audubon’s shearwater (*Puffinus lherminieri*) that Saba is most noted.

Red-billed tropicbird are a flagship species for Saba and conservation of this species is addressed in the Nature & Environment Policy Plan Caribbean Netherlands 2020 -2030[2] (unpublished).

[1] Measured by a wave measurement buoy, deployed by the Governmental Harbor Development Organization from February 2020 to April 2021

[2] https://english.rijksdienstcn.com/documents/publications/ezk/nature-and-environment-policy-plan/nature-and-environment-policy-plan/index

The Saban breeding population of red-billed tropicbird is estimated at 1.100-1.700 breeding birds and is possibly declining (Boeken and Leopold, 2020). The population amounts to more than 1% of the global population and more than 35% of the West Indian population (Birdlife International, 2021; Geelhoed et al. 2013; Boeken 2016, Boeken and Leopold, 2020). The Important Bird Area along the coast of Saba (AN006) harbors the largest amount of breeding red-billed tropicbird in the America's. Red-billed tropicbird live in isolated colonies. In 2019 the Great Level colony amounted to 28-60 birds and St. Johns Cliffs colony to 42-89 birds (Boeken and Leopold, 2020). According to these authors, the colonies on Saba are threatened with extinction. Predation by rats and feral cats is a serious threat on Saba.
Small groups of red-billed tropicbirds can be observed along the coast, especially in the late afternoon. Outside the breeding season the birds spend all their time at sea. During breeding they leave the island for feeding during the day to return in the late afternoon (highest numbers counted at 16.00 hrs, Boeken, 2016).

For Audubon's shearwater, the Muriel Thissell Park at the north side of Mt. Scenery is the only confirmed, current breeding site.
The number of breeding birds is very difficult to estimate and varies from 15-25 pairs (Lee and Mackin, 2009; Bradley and Norton, 2009) to 1000 individuals (not pairs, Lee, 2000). Audubon's shearwater are the National Bird of Saba, are protected by the SPAW Protocol (Annex II species) and are considered a Flagship species (MacRae et al, 2021).

Brown pelicans (*Pelecanus occidentalis*) have been observed in the area. The brown pelican and the Audubon's shearwater are protected under Annex II of the SPAW Protocol.

Figure 4.6: Top left: red-billed tropicbird *Phaethon aethereus* (photo Brenda and Duncan Kirkby); top right: brown pelican (*Pelecanus occidentalis*) and bottom left: Audubon's shearwater *Puffinus lherminieri*

Table 4.1: IBA trigger species in IBA Saba coastline (BirdLife International 2012, in Geelhoed, 2013)

Audubon's shearwater	*Puffinus lherminieri*
Red-billed tropicbird	*Phaethon aethereus*
Bridled-quail dove	*Geotrygon mystacea*
Purple-throated Carib	*Eulampis jugularis*
Green-throated Carib	*Eulampis holosericeus*
Antillean crested hummingbird	*Orthorhyncus cristatus*
Caribbean elaenia	*Elaenia martinica*
Scaly breasted thrasher	*Margarops fuscus*
Lesser Antillean bullfinch	*Loxigilla noctis*

Other bird species observed in the Giles Quarter area are: American osprey (*Pandion haliaetus carolinensis*), magnificent frigatebird (*Fregata magnificens,* red-tailed hawk (*Buteo jamaicensis*), Zenaida dove (*Zenaida aurita,* a restricted range species*),* American Kestrel (*Flaco spaeverius caribaearm),* brown booby *(Sula Leucogaster),* black-necked stilt (*Himantopus mexicanus*), American oystercatcher (*Haematopus palliatus*), semipalmated plover (*Charadrius semipalmatus*), ruddy turnstone (*Arenaria interpres*), ring-billed gull (*Larus delawarensis*), snowy egret (*Egretta thula*), and house sparrow (*Passer domesticus*) (source: Observation.org, 2017-2020; Boeken, 2018; D. Hassel, 2020, annex 2c); MacRae et al, 2021).

Other terrestrial fauna

Other terrestrial fauna of conservation importance include three iguana species, four lizards and one snake all of which are believed to be found at the development site (MacRae et al, 2021):

- The Lesser Antillean Iguana (*Iguana delicatissima*), an IUCN Red List Critically endangered species is believed to be present within the study site, but possibly extirpated;
- The Melanistic Lesser Antilles Iguana (*Iguana melanoderma*), known to be present in the study site is thought to be endemic and endangered, due to its restricted range, habitat loss and hybridization with accidentally imported *Iguana iguana*;
- The Red bellied racer snake (*Alsophis rufiventris*) has a restricted range and is an IUCN Red List species considered Vulnerable to extinction.

The single endemic vertebrate is *Anolis sabanus*. The gecko *Sphaerodactylus sabanus* has a restricted range. Hunting has caused The Mountain Crab Gecarcinus ruricola to now be considered endangered on the island. The bat subspecies *Natalus stramineus stramineus* is endemic to Saba (Collier and Brown, 2008; in MacRae, 2021, annex 2a).

4.3.2 Ecological survey of project area

Vegetation

The vegetation survey by Saba Conservation Foundation was carried out in a rectangular area of approximately 300x350 meters, north of the beach where the harbor is projected (see figure 1.2). Table 4.3 shows the tree species found in the research area and the respective numbers observed. Figure 4.7 shows the locations of trees with a stem circumference at breast height (CBH) of 30-50 cm; figure 4.8 shows trees with a CBH of more than 50 cm. Annex 2a gives more detailed information on the recorded trees (including pictures).

Table 4.3: Tree species identified by Saba Conservation Foundation Staff (source: MacRae et al., 2021)

Common name	species	30-50 cm CBH	>50 cm CBH
Acacia	*		1
Ficus	**		6
Fiddle Wood, Susan Berry	*Citharexylum spinosum*		1
Gumbo Limbo	*Bursera simaruba*		8
Loblolly	*Guapira fragrans*		22
Manchineel	*Hippomane mancinella*	79	62
Quadrella	*Cappares indica*	2	14
Unidentified		62	18
Total		**143**	**162**

* possibly *Acacia farnesiana* (*casha*)
** possibly *Ficus citrifolia*

The dominant tree species in the area are Manchineel (*Hippomane mancinella*) which form notable forests within the survey site but outside (mostly to the east of) the footprint of the harbor project. This is an unusual vegetation type for Saba (see annex 2a).
The Bastard tobacco (*Cordia nesophila*) is a tree with a restricted range found within the study site.

In total 32 rare species were identified by Saba Conservation Foundation based on The Landscape Ecological Vegetation Map of Saba (De Freitas et.al., 2016), of which 8 occur in the Aristida-Mitracarpus vegetation type (the main vegetation type in the area): Egyptian crowfoot grass (*Dactyloctenium aegyptium*), Cana gorda girdlepod (*Mitracarpus polyclades*), silver fern (*Pityrogramma calomelanos*), snapdragon root (*Ruellia tuberosa*), spreading fanpetals (*Sida abutifolia*), Caribbean stylo (*Stylosanthes hamata*), Blue wiss (*Teramnus labialis*) and creeping ox-eye (*Wedelia calycina*). The Cana gorda girdlepod (*Mitracarpus polyclades*) is an endangered species which is known to be endemic to Puerto Rico and Saba.

Figure 4.7: Trees recorded with 30 cm – 50 cm CBH (source: MacRae et al, 2021). Harbour and dam layout are indicative in this figure and are based on an earlier design iteration.

Figure 4.8: Trees recorded with CBH > 50 cm (source: MacRae et al, 2021). Harbour and dam layout are indicative in this figure and are based on an earlier design iteration.

Birds

The area for the bird survey is approximately 500x650 meters (see figure 1.2)and includes steep, inaccessible cliffs, particularly near the settlement of St. Johns, which are favored by nesting seabirds.
During the vegetation survey, field observations of birds present were made by the SCF staff. Species observed included:

- Red-billed tropicbirds; SCF staff estimated the presence 80-100 nests on the hillside south of St Johns;
- Audobon's shearwater have been found nesting on the inaccessible slopes in the north east of the survey area near St Johns. Although, according to literature the only nesting site is Muriel Thissell Park;
- Swallows;
- Zenaida doves (*Zenaida aurita*).

The Great Level (southwest of St. Johns) has been identified as one of four important Sea Bird Nesting sites on Saba (Wulf, Saba Conservation Foundation).

4.4 Marine ecological values

4.4.1 Summary of literature

General description

In general, on the islands of the Windward group development of coral reefs is poor. In shallow areas, *Acropora palmata* can form shallow reefs, but in general, the corals occur scattered on the bottoms and on large boulders. Near steep slopes, corals are usually packed slightly more densely (Bak 1977).

On Saba, five types of reef structures can be distinguished: 1) seamounts or pinnacles, 2) deep patch reefs, 3) encrusted boulders, 4) walls, and 5) true reefs (Van't Hof, 1991). Kuramae and Rouendal (2013) presented a classification of true reefs and patch reefs (dense and diffuse, see figure 4.9). True reefs are only found at a few locations within the Marine Park (e.g. Tent Reef, East of Giles Quarter). The vast majority of coral structures can be categorized as "coral encrusted boulders". These boulders are volcanic in origin and generally originate from the hillsides along the coast. Both hard and soft corals and sponges cover these boulders.
The coral reef around Saba has deteriorated seriously in the past 25 years. Coral cover declined from 30% in the '90s to a current cover of 8% (values between 2 en 14%, Meesters et al., 2019).

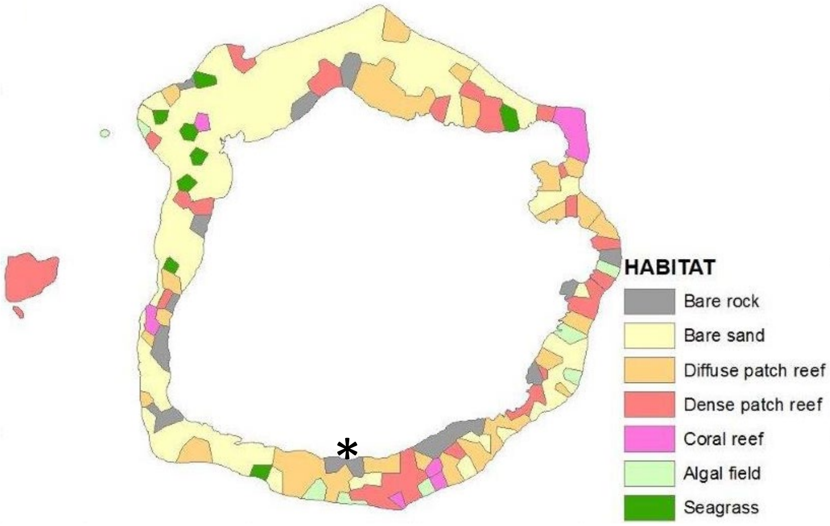


Figure 4.9: Characterization of sea floor (Kuramae et al., 2013). Proposed harbor location indicated by asterisk.

From the benthic seascape map of Saba (Kuramae et al., 2013, figure 4.9), it can be concluded that in the direct vicinity of the Black Rocks location, the seafloor consists of bare rock and diffuse patch reefs. Important marine values are present in the area east of the Black Rocks area: dense patch reefs and true coral reefs, approximately 250m – 750m eastward of the proposed harbor.

Reef Health

Van der Vlugt (2016) used the Reef Health Index (Healthy Reef Initiative, 2015, 2018) on 20 dive sites on Saba, to produce an overall score on reef health in Saba. The criteria used for this study were: coral cover (in %), macro algae cover (in %), and presence of herbivorous species and commercial fish (in g/100m2). The overall health of the reefs on Saba is 'fair', according to this RHI score.

In the direct vicinity of Black Rocks, 3 dive sites have been studied for marine benthos and occurrence of fish. These sites are (see also figure 4.10):

- Greer Gut: N17°36'42.54 W63°14'30.30
- Big Rock Market N17°36'45.06 W63°14'10.44
- Giles Quarter Shallow: N17°36'42.60 W63°14'28.80

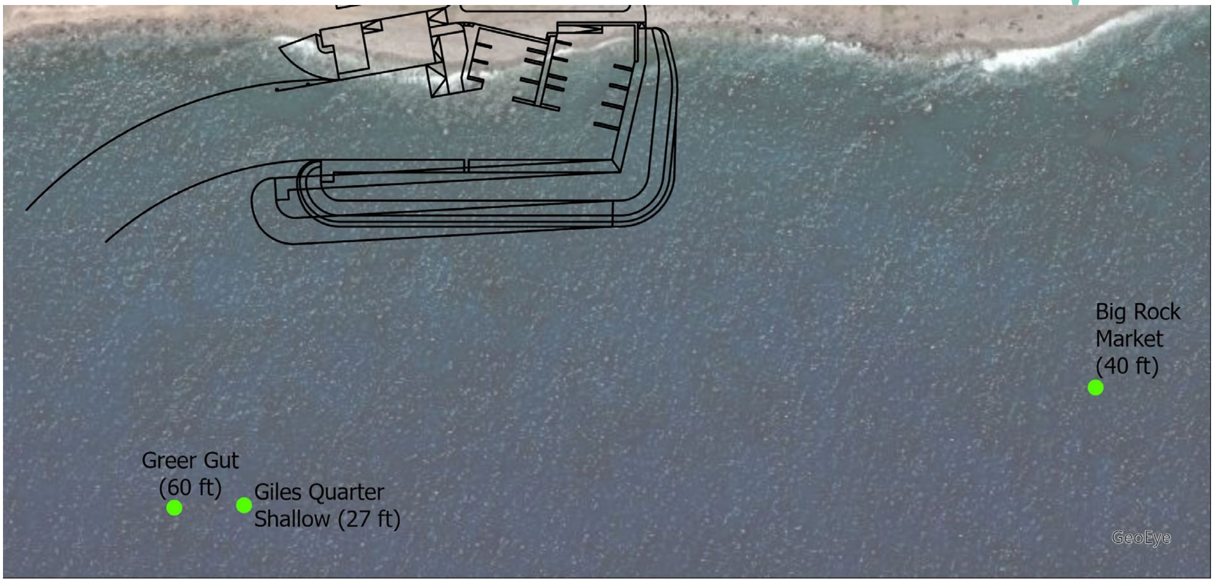


Figure 4.10: Dive sites near the proposed harbor location, studied determination of Reef Health Index

According to Van der Vlugt in 2016, overall reef health in these nearby dive sites is "poor" (on a scale of critical-poor-fair-good-very good). The scores for "coral cover" only in 2015 was found to be "critical" for all three sites: values were 2% (Giles Quarter Shallows), 2,5% (Big Rock Market) and 2,9% (Greer Gut). In 2016, measured values were slightly higher (Hildebrand, 2017).
In annex 7 a table of the scores of the Saba dives sites is presented (from Van der Vlugt, 2016 and Hildebrand, 2017).

Fish and turtles

Ecological surveys have recorded over 150 fish species in Saba, all with healthy populations. The enforcement of strict fishing regulations has led to large number of Nassau groupers, graysby's, hinds and coneys.
Parrotfish, triggerfish, angelfish, snapper and grunts are very common in the Saban waters. Schooling fish include wrasses, blue tangs, chromis and surgeonfish. In sandy areas, lizardfish, sand divers, flying gurnards and garden eels predominate[1]. Common species of pelagic fish are horse-eye jacks, great barracuda, wahoo, tarpon and a number of species of sharks. Black tip reef sharks, grey reef sharks and nurse sharks are the most common species sighted. Hammerhead sharks and whale sharks are more rare. All 5 shark species are listed on Annex III of the SPAW Protocol and their stocks should be managed sustainably.

In the Giles Quarter area several critically endangered (CE) and endangered (E) fish species have been observed in the past, such as warsaw grouper (*Hyporthodus nigritus* CE), Nassau Grouper (*Epinephelus striatus*, E), Barndoor Skate (*Dipturus laevis*, E) and Winter Skate (*Leucoraja ocellate*, E, see also annex 2c).
The dive sites Greer Gut, Big Rock Market and Giles Quarter Shallow (see figure 4.10) have been studied for occurrence of fish (Van der Vlugt, 2016, Hildebrand, 2017). Presence of key herbivorous fish was "good" at Giles Quarter Shallow (3353 g/100m2), at the two other reefs it was "poor" (1586 g/100m2 at Greer Gut and 1423 g/100m2 at Big Rock Market).

Both green turtles (*Chelonia mydas*) and hawksbill turtles (*Eretmochelys imbricata*) occur around Saba. These 2 species are listed on Annex II of the SPAW Protocol, which means they should be subject to "total protection and recovery". Loggerhead and Leatherback are infrequent guests on Saba, Kemp's Ridley turtle and Olive Ridley turtle do not occur on the island (Widecast[2]).

[1] Source: Saba Conservation Foundation website
[2] https://www.widecast.org/who-we-are/widecast-ccs/saba/

Nesting by green turtles and hawksbill turtles occurs infrequently on Saba, the only suitable nesting location is Well's Bay beach (WideCast, Swinkels, 2004), but also at Cove Bay nests have been found (in 2021). The area between Giles Quarter and Fort Bay is an important foraging area for the Hawksbill turtle (Swinkels, 2004). The current conservation status of Saba's sea turtles is "very unfavorable" because of decreasing water quality, decreasing food supplies and eroded beaches. The quality of seagrass beds around Saba is essential for food supply and needs to be monitored (DCNA, 2019).

Besides fish and turtles, conch, lobster and a variety of crabs can be observed in the area.

Marine mammals

Saba and the Saba bank are known to host a variety of marine mammals. The Saba National Marine Park classifies as part of the Yarari Marine Mammal and Shark Sanctuary, established officially on 2 September 2015 serving as a sanctuary for critical activities of the marine mammals (feeding, calving, mating, Debrot et al, 2017).
Near Saba 8 species are known to occur, but this may become more with progressing research (Debrot, 2017). Table 4.2 presents the likely occurrence, reported sightings/observations and unlikely occurrences. It can be noted that during the first half of the year more sightings of marine mammals have been reported than during the second half of the year. Occurrence during the second half of the year is unlikely for the humpback whale and the common minke whale.

Table 4.2: Temporal distribution of species known to occur in the Windward Dutch Caribbean (Debrot 2017).

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Likely residents												
Bottlenose dolphin	?	X	?	X	X	X	?	X	?	X	?	?
Spinner dolphin	?	?	X	X	X	X	?	?	?	?	?	?
Atlantic spotted dolphin	?	?	?	?	?	?	?	?	?	?	?	?
Short-finned pilot whale	?	?	X	?	X	?	?	?	?	?	X	?
Cuvier's beaked whale	?	?	?	?	?	X	?	?	?	?	?	?
Seasonal presence												
Humpback whale	X	X	X	X	X	X	O	O	O	X	O	O
Common minke whale	O	X	X	X	O	O	O	O	O	O	O	O
Sperm whale	X	X	X	?	?	?	?	?	?	?	?	?
?: Likely occurrence; X: Reported sightings/observations; O: Unlikely occurrence												

Marine mammals regularly spotted outside the current harbor (Fort Bay) and the Giles Quarter area are humpback whales and bottlenose dolphins. They are usually observed at distances of more than 150 meters away from the coast.

Some additional information of interest for the EIA has been collected from various sources:

- Most sightings of whales on Saba are during the winter months, January to March, with a peak in March; the majority of the sightings being of humpback whales (Scheidat et al, 2015; Debrot et al, 2017);
- Dolphins have been observed year-round, and equally during winter months and summer months (Debrot et al, 2013), with the exception of a distinct peak in March (Scheidat et al, 2015). Summer is their reproducing season (FAO, 1993);
- The short-finned pilot whale is a deep diver, and lives mostly in deeper waters, near the edge of continental shelves;
- The humpback whale is calving near Saba (possibly at the Saba Bank) during winter months; highest number of recordings are in March (Debrot 2017);
- Debrot et al. (2011) report that humpback whales sightings amounted to 45% of all records (of sea mammals) around the windward Dutch islands.
- The common minke whale are known to be relatively close to the shore during winter months;

- The sperm whale is common in the waters around Saba but they are largely restricted to deeper waters where they prey on deep water squid. Most sightings in Saba have been in the first quarter of the year.
- Relatively little information is available on the Cuvier's beaked whale.

4.4.2 Ecological survey of project area

In February 2020, Saba Conservation Foundation (SCF) assessed marine ecological values in an area of 300 meters East of the footprint of the new harbor and 500 meters West of the footprint. The study involved:

1. mapping of seafloor (by SCF)
2. mapping of colonies of protected species (Acropora and Montastraea species, by SCF)
3. assessment of coral cover and coral species in footprint of proposed harbor and in nearest patch reef (by EcoVision)

Mapping of seafloor

The seafloor in the area of the projected harbor was mapped by SCF in an area of 800m by 250m, including the footprint area. This was done snorkelling by taking waypoints and classifying the seafloor at these points.
The seafloor in the area consists of sand, boulders, sand with boulders interspersed, patch reefs and patch reefs covered with boulders (see figure 4.11 for photographs). Figure 4.12 shows the spatial distribution of the different seafloor-types.
The area up to 7 meters of water depth is generally covered with boulders, the patch reefs are, with some exceptions, present in the waters deeper than 10 meters.
The footprint of the projected harbor is entirely in the area covered with boulders. This area has a very low cover of hard corals (1,6%, see next section).

Mapping of colonies of protected species

Since December 9, 2014, four coral species have been listed on the Annex II list of the SPAW protocol, meaning that the Government needs to secure "total protection and recovery" for these species (see also Chapter 2). The species are *Acropora palmata, Acropora cervicornis, Orbicella annularis* and *Orbicella faveolata*.
In figure 4.13 the locations of the colonies of these 4 species are mapped. The dimensions of the observed colonies (in cm x cm) and the coordinates of the colonies are summarized in annex 2b. As can be concluded from the annex and figure 4.13, a concentration of *A. palmata* is present in the footprint of the breakwater and the harbor approach channel. In this area also the largest specimens of *A. palmata* have been found. A second concentration of colonies of *A. palmata* is present just east of the projected breakwater.

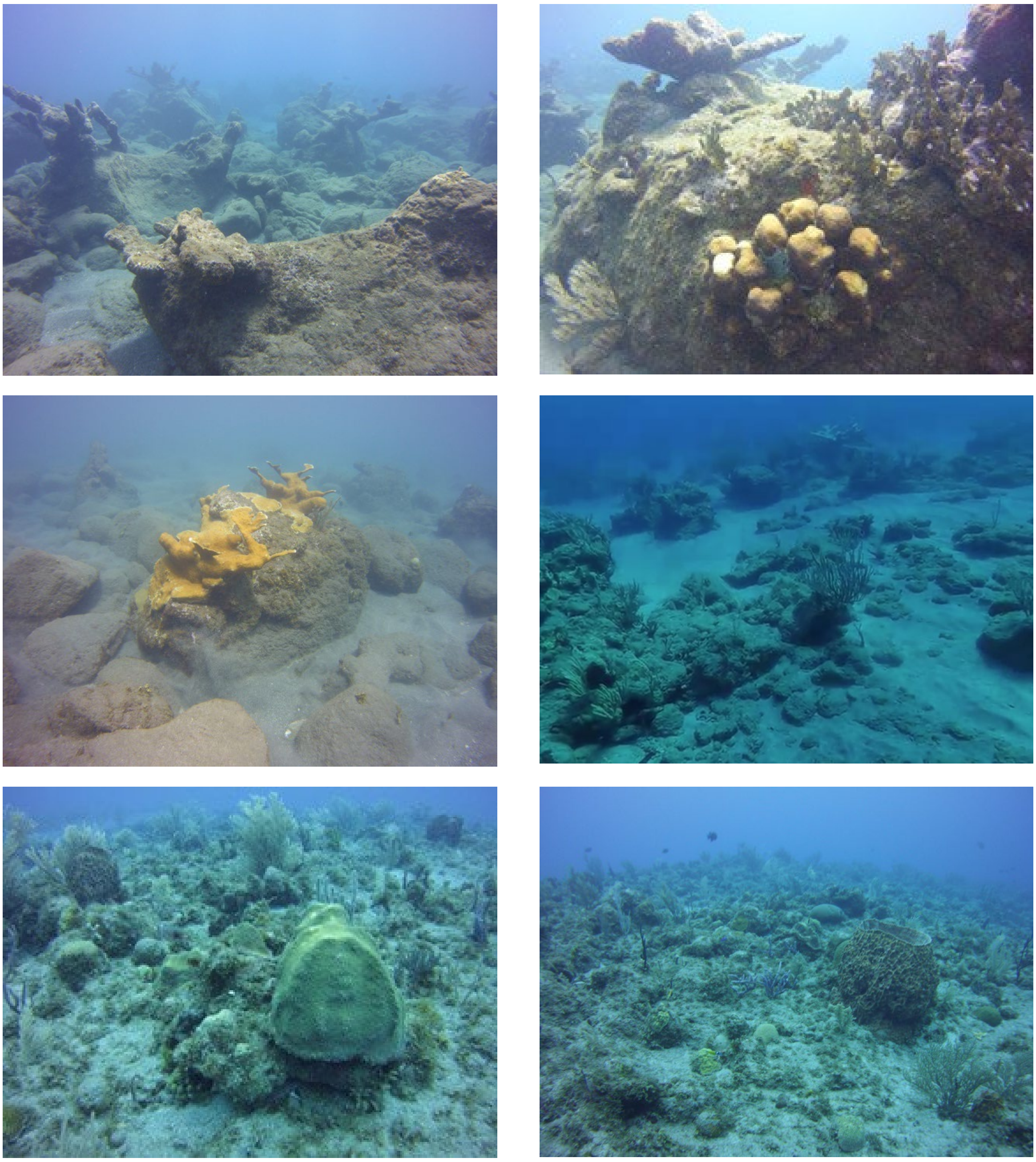


Figure 4.11 Top photos and mid-left: shallow area covered with boulders (0-7 m). Mid-right: area of patch reef covered with boulders. Bottom: deeper area with patch reef (10m+)

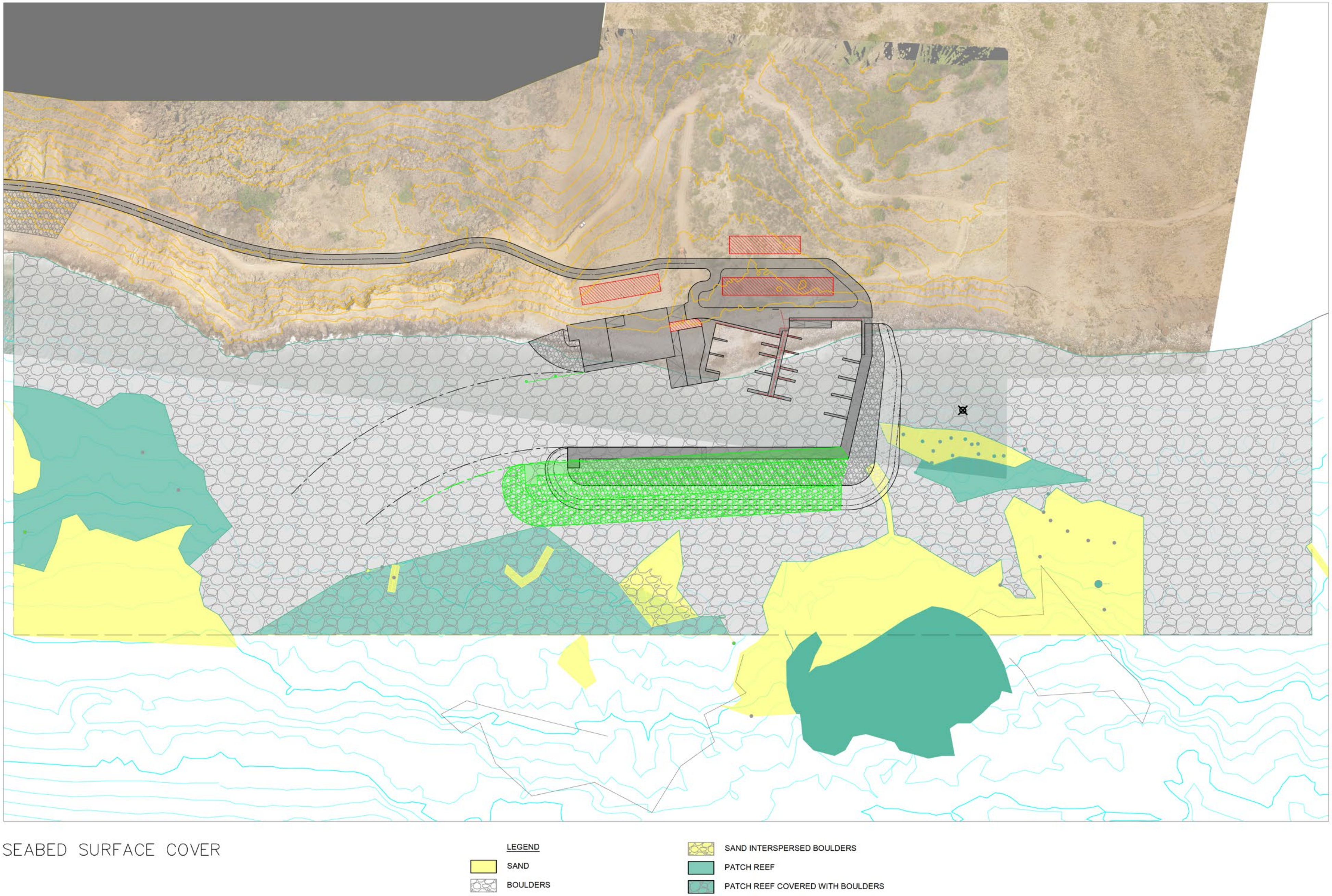


Figure 4.12: Seabed characterization and coral survey by SCF, February 2020

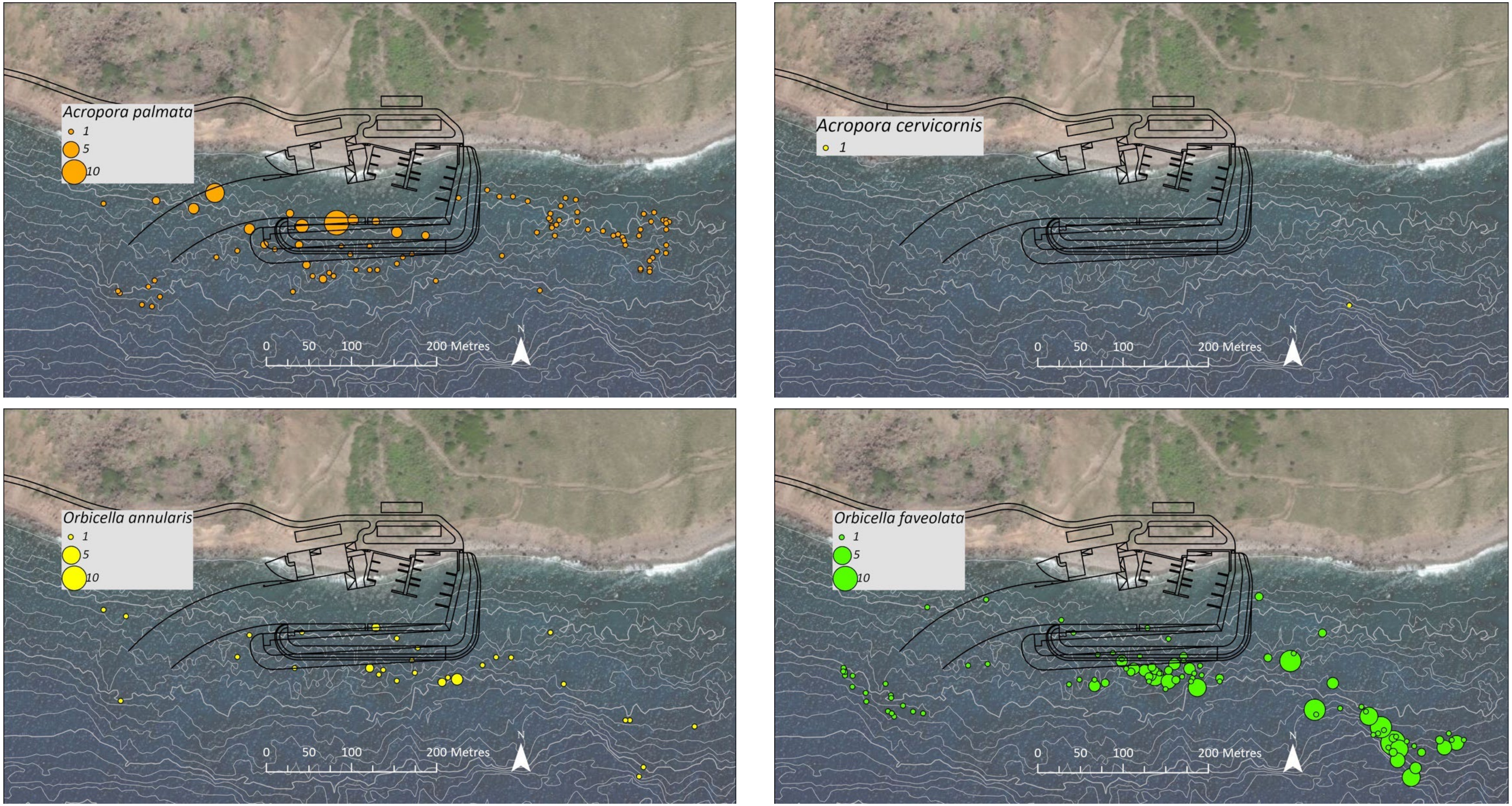


Figure 4.13 Distribution of colonies of protected species (dots give indication of numbers). SCF, February 2020

In total 118 colonies of *Acropora palmata* have been counted in the 800x250m area. *A. cervicornis* is almost absent (1 colony southeast of the projected breakwater).
M. annularis (34 counted) is present in a small concentration in the footprint area, and a more significant concentration just south of the projected breakwater, while the distribution of *M. faveolata* (187 counted) is mainly in deeper waters (between 10 and 15m), south and southeast of the projected breakwater. *M. cavernosa* (not protected, vulnerable, 17 counted) is present in small concentrations in and near the footprint area and west of the projected breakwater. *D. cylindrus* (14 counted) is present near the projected approach channel and southeast of the breakwater. The latter 2 species are not indicated on the map in figure 4.13.

Coral cover and coral species in footprint and nearby patch reef

Coral cover and occurrence of coral species were assessed by taking photoquadrats on 6 shallow water transects (4-7 meters, footprint of proposed breakwater) and 10 deeper water transects (10-15 meters, a nearby patch reef). In figure 4.14 the locations are mapped. The photographic output was analyzed with CPCe using 40 random points per photoquadrat.
Coral cover in the footprint area is 1.6%. The corals that are present in this area are: brain corals (mostly *Diploria strigosa* and *Colpophyllia natans*), fire coral (mostly *Millepora complanata*), elkhorn coral (*Acropora palmata*) and star corals (*Montastraea annularis* and *M. faveolata*). Additionally small numbers of Gorgonians (soft corals) are present.
In the deeper patch reef, a more divers coral community is present, including species such as: *Montastraea annularis*, *M. faveolata, M. cavernosa, Dendrogyra cylindrus, Diploria strigosa, Diploria labyrinthiformis, Porites astreoides*, *P. porites*, *Siderastrea siderea*.

The following observations were made in the patch reef (see also annex 2d):

- Scleractinian coral cover ranged from 1.2%-5.3% across all transects, with an overall average of 3.2%;
- 23 hard coral species identified, with an average of 13 species per transect ;
- Siderastrea, Orbicella and Porites were the most commonly found genera;
- Corals of the Meandrinidae family were notably rare for the habitats explored;
- Calcifying hydrozoa (Millepora sp.) were found in all transects, and in 84/250 quadrats (33.6%);
- Very little evidence of coral recruitment was found with only two recruits (<2cm diameter) observed, although this was difficult to confirm from aerial view images;
- Disease in hard corals was only observed in 4/250 quadrats (black band disease);
- Algae (average cover 26%) was observed to be growing over corals, sponges or hard substrate in ~90% of all photoquadrats analysed and appeared to be spreading with healthy and recent growth;
- No hard substrate with healthy crustose coralline algae growth (without turf algae or cyanobacteria) was observed;
- Cyanobacterial mats were observed in all transects;
- The images analysed showed very little reef structure, with 76.4% of quadrats being classified as having no structure (just sand), very low or low reef structure;
- While the soft coral cover captured using randomised points was low (1.6%), soft corals were found to be present in 26% of all photoquadrats and were found in 9/10 transects;
- Cover of sponges was found to be 3.2%. The species of sponges most observed were the branching tube sponge (*Pseudoceratina crassa*) and the giant barrel sponge (*Xestospongia muta*).

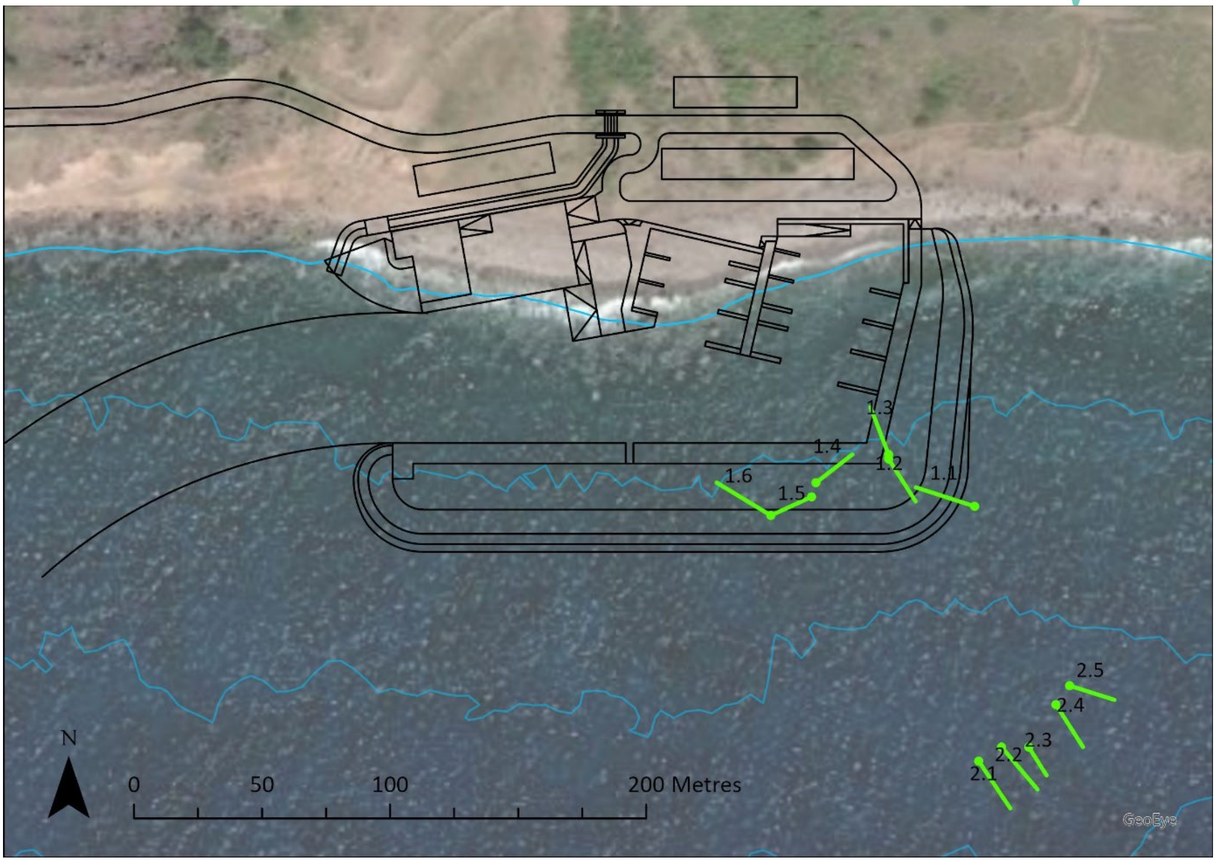


Figure 4.14: Location of transects (5 transects have been photographed in the area of 1.1-1.5 and 10 transects have been photographed in the area of 2.1-2.5)

4.5 Protected species and species of conservation importance

In table 4.3 a summary is given of protected species occurring in and near the project area, or are likely to occur near the project area. Annex 2a and annex 2c present lists of species with their conservation status (terrestrial and marine species respectively).

Table 4.3: Saba's protected species and occurrence near project site

Protected Species	Protection status	Occurrence near project site
Brown pelican, Audubon shearwater, Roseate tern	SPAW Annex II	Pelican: observed; other species occasionally near project site
Green turtle, hawksbill turtle	SPAW Annex II; CMS Appendix II; Interamerican Sea Turtle Convention	Observed near project site
Whales and dolphins, mostly hump-back whales and bottlenose dolphins	SPAW Annex II; CMS Appendix I (Humpback whale)	Occasionally near project site
Whale shark and other sharks	CMS Appendix II	Occasionally near project site (assumed)
Corals: *Acropora palmata, A. cervicornis, Montastraea annularis* and *M. faveolata*	SPAW Annex II	Significant numbers in and near footprint area; 1 single colony of *A. cervicornis*

4.6 Climate change

A summary of the likely impacts of climate change can be found in "Climate change effects on the biodiversity of the BES islands" (Debrot and Bugter, 2010).

According to the Small Islands section of the IPCC fourth assessment report, temperatures in the Caribbean region are expected to increase between 1.4 to 3.2 °C this century.

Globally a likely increase (> 66%) in hurricane intensity with larger peak wind speeds and heavier precipitation (IPCC, 2007) is predicted. Storm surge height is associated with hurricane intensity and is therefore also likely to increase. The range of inundation and capacity for coastal erosion will increase even more as the sea level rises.

The number of flood events is also expected to increase; the picture for droughts is unclear regionally. A rise in extreme weather events with high rainfall is projected to happen across the Caribbean. Research has shown Hurricane Maria had a return period of 115 years; projecting this to a 1.5 ◦C warmer world a similar hurricane rainfall event would become a one in 75-year event and a one in 43-year event for the 2 °C scenario (Vosper et al., 2020).

5 Impacts in footprint of project

The footprint area is defined as the area occupied by the physical structures as well as excavated and dredged areas. It is assumed that in the footprint all vegetation and marine benthos (sessile fauna) will be lost, except for situations where relocation of important ecological elements is possible, such as the relocation of protected corals (SPAW Protocol Annex II species) in the footprint of the breakwater and an adjacent high-risk area[1].
In the following paragraphs impacts from loss of ecological values in the footprint (and a high-risk area near the breakwater) will be described. Impact assessment has been carried out with a qualitative method. Classification of impacts takes place according to the following labels: “severe”, “possibly severe”, “significant”, “moderate”, “low” and “insignificant”. Classification will take place for both unmitigated and mitigated impacts.

5.1 Footprint of access road

General

The access road to the proposed harbor will have a length of approximately 800 meters and a width of 7-8 meters. For a large part, approximately 500 meters (section 2 and 3), the construction of the access road takes place by renovation of an old unpaved road, which was partly collapsed. This part of the existing road is located in a heavily eroded area (section 2) and an area where a low growing vegetation is present, consisting of grass, low shrubs and a few trees (section 3 and 4).
The first section of the new access road of approximately 150 meters (near the gas station) and the last 150 meters (near the harbor area, section 4) are to be constructed as new, partly in the natural landscape. A stretch of approximately 350 meters along the coast serves as a temporary road, needed for construction (see chapter 3).

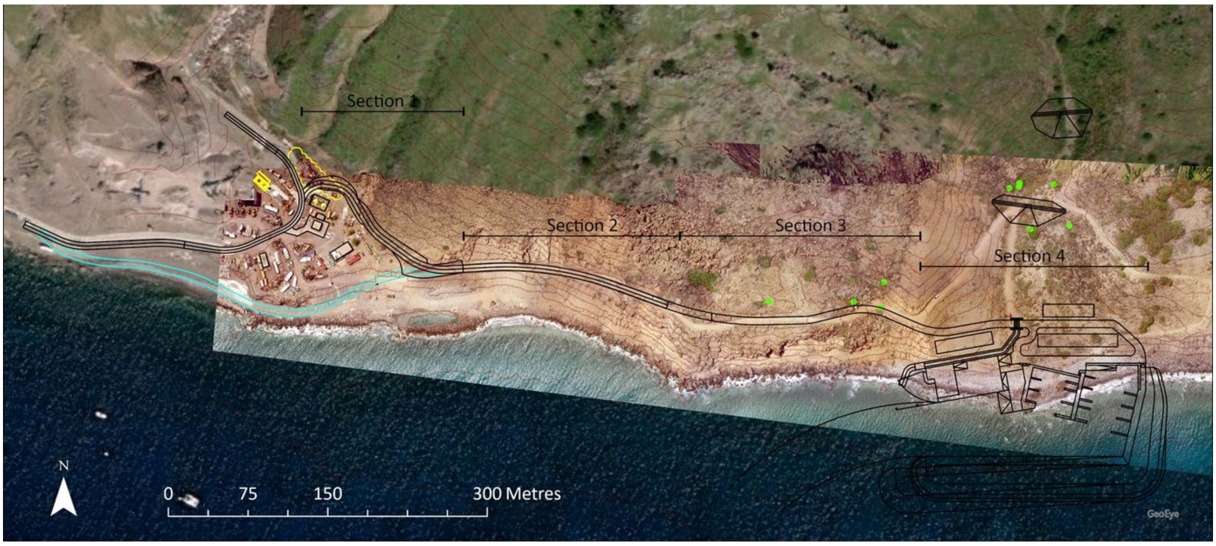


Figure 5.1: Sections 1-4 of new road. Road indicated in blue is the temporary road. Green dots: mature trees.

Temporary road

The temporary connection between the current harbour road and the main road to the Black Rocks area is a 350 meters section, projected in the direct vicinity of the coastline, which is mostly flat land. For the large part, this section follows an existing, unpaved road of 3m wide (see figure 5.2 and 5.3),

[1] Selection of relocation area is based on a relocation trial project (2 locations tested)

which needs to be widened to approximately 4 meters. In the east part of this section, a connection will be made between the temporary road and the main road. At this point, the hillside is severely degraded, there are several locations where rocks have been dumped (see figure 5.3). In this steeper area, profiling of the hillside is necessary to create space for the road-connection (approximately 5 meters on both sides of the road for 50 meters). The footprint is entirely in bare rock, ecologically important elements were not observed in this part of the footprint.

Section 1: Connection near gas station

The final connection between the current harbour road to the Black Rocks area, which is an entirely new section of 150 meters, passes just north of the gas station (figure 5.2). As stated in chapter 3, the fuel tanks of the gas station need to be relocated to realize this connection. The environmental impact of this relocation is not in the scope of this EIA.
The road connection partly runs through a current scrap yard, that will be removed and partly through an intact part of the hillside (see figure 5.4 and 5.5). The road will have a width of 7-8 meters. About 4 meters on north-east side and virtually zero on the other side are needed for profiling of the hillside (total width of footprint: 18m). The hill in the east part of section 1 can best be characterized as grass land (main species: *Aristida adscensionis* and *Bothriochloa pertusa*) with few flowering species (mainly *Pentalinon luteum*, hammock viper's tail) interspersed. Ecologically important elements such as high trees have not been observed in the footprint.

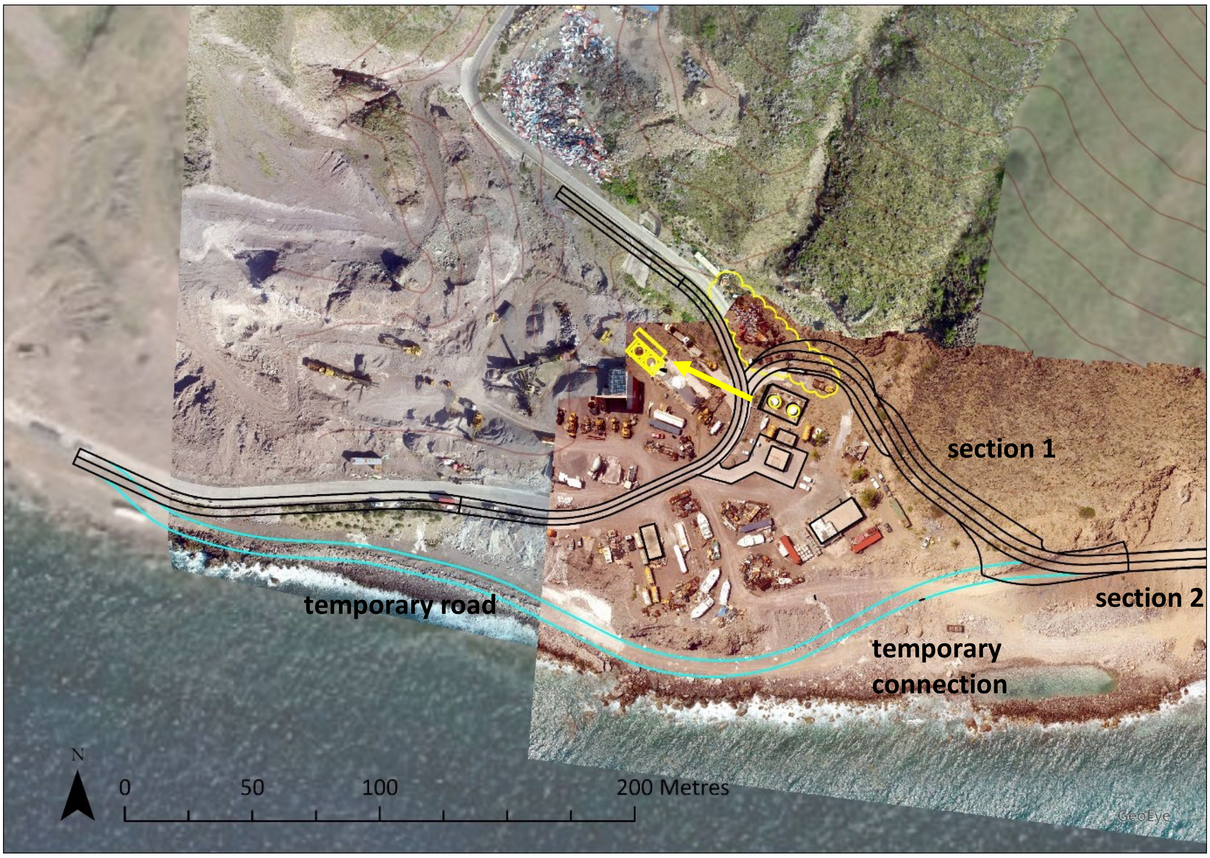


Figure 5.2: Temporary road with connection, in blue color. Main road (section 1 and 2). Yellow arrow: relocation of gasoline and diesel tanks before construction of section. Yellow area: scrap yard.

Figure 5.3: Temporary road, main road (section 2) and temporary connection


Figure 5.4: Main road section 1, partly through scrap yard and partly through hill vegetation

Figure 5.5: Top left: characterization of western part of section 1 (road connection north of gas station with scrap yard). Right: eastern part of section 1 (natural vegetation, grass land) and few shrubs. Bottom left: *Pentalinon luteum* (hammock viper's tail)

Section 2

Section 2 (225 meters long) is the section where the road crosses the steepest part of the hillside (steepness of road 13-16%). In this area most benching and slope-profiling need to take place. Figure 5.8 (cross section) shows that the total footprint of the road and slope profiling in this part is approximately 30-50 meters wide (horizontally), which includes a safety bench of 6-8 meters wide. This part of the footprint is in a heavily eroded environment. South of the road vegetation is virtually absent. North of the road a secondary grass and shrub vegetation is present. Part of this vegetation was already removed in earlier construction activities, part of this vegetation still needs to be cleared for profiling of the slope of the hill (see figure 5.7). As can be seen in figure 5.7 construction in this section already started.

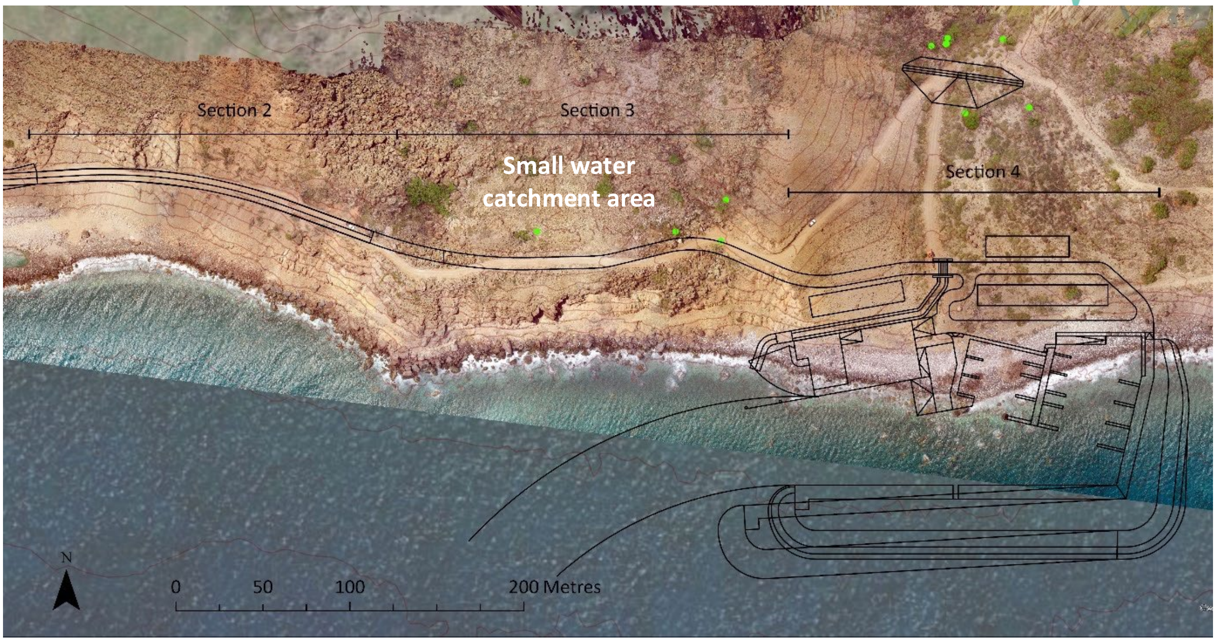


Figure 5.6: Main road to Black Rocks area (sections 2, 3 and 4). Green dots are mature trees

Figure 5.7: Section 2: Existing unpaved road (a), safety bench (b), hillside profiling (c). (d): part of the vegetation that still needs to be cleared. In the right part of the picture, near the shore line, the construction of the rock revetment is visible (e).

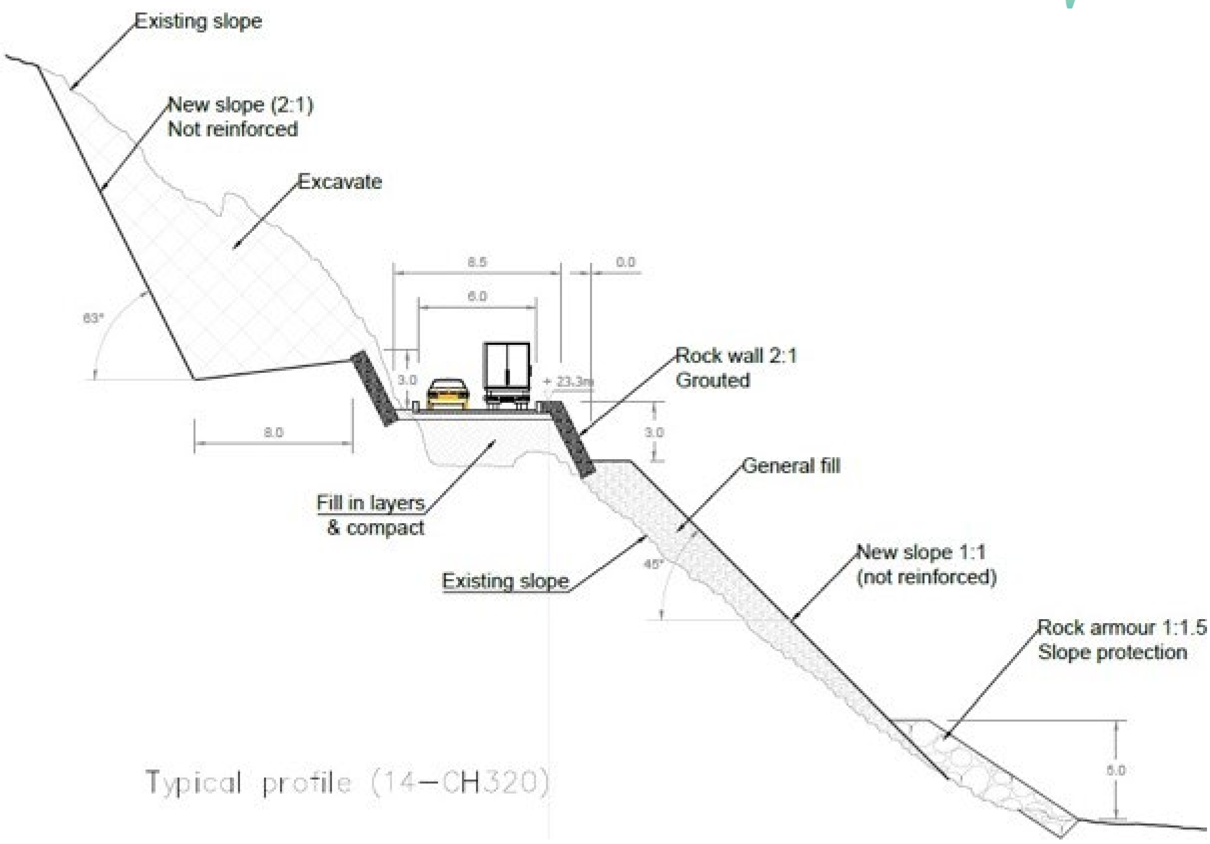


Figure 5.8: Section 2, cross section

Section 3

Section 3 (275 meters long) runs through parts of the hillside that are less damaged. Also, this part is less steep, and the footprint of the road is less wide (10-25m wide, including slope profiling). On both sides of the projected road a secondary shrub vegetation is present, consisting of maran bush (*Croton flavens*), black cherry (*Randia aculeata*), several grass species such as *Aristida adscensionis* and *Bothriochloa pertusa*. Periwinkle (*Catharanthus roseus*), Cana gorda girdle pod (*Mitracarpus polycladus*[1]), bay with (*Pentalinon luteum*) and Turk's cap cactus (*Melocactus intortus*, endemic for Saba, Statia and Sint Maarten) also occur. This vegetation - as far as situated in the footprint - needs to be cleared. In this section, also four trees (of which 2 manchineel trees) are present in or near the footprint (figure 5.6 and 5.9). No protected species have been observed in this section of the footprint.

Just north of the projected road, a natural depression in the landscape occurs. This area has both ecological importance and hydrological importance. It functions as a (small) catchment area for storm water and several large mature trees are present (see figure 5.6). This area should be excluded from the footprint and kept intact as much as possible.

[1] Endangered and endemic species to Saba

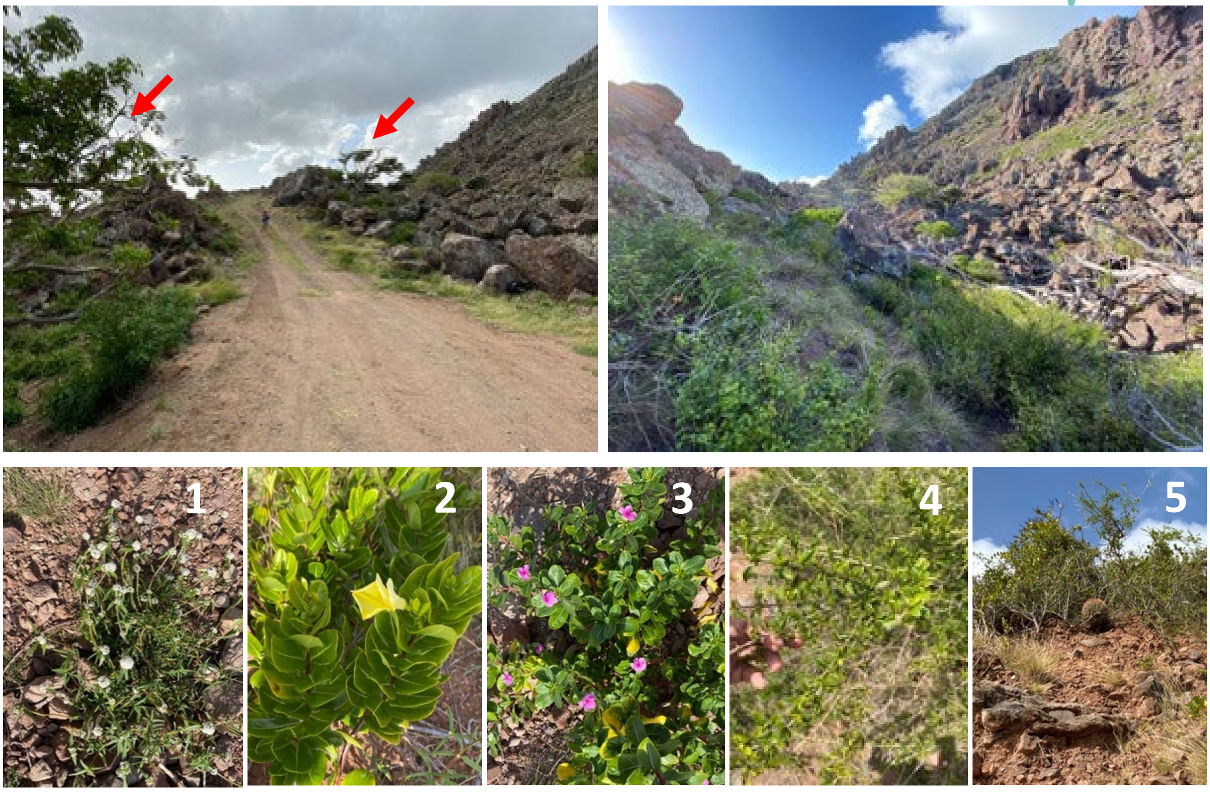


Figure 5.9: Impression of section 3 and species occurring. Top left: 2 manchineel trees. Top right: depression in landscape just north of projected road with several large trees (most manchineel). Bottom: examples of species occurring in section 3: (1) cana gorda girdle pod (*Mitracarpus polycladus*); (2) hammock viper's tail (*Pentalinon luteum*), (3) periwinkle (*Catharanthus roseus*), (4) black cherry (*Randia aculeata*) and (5) Turk's cap cactus (*Melocactus intortus)*

Section 4

In the last 150 meters of the access road to the harbour (Section 4), no unpaved road is present, the road will be constructed as new. This new section crosses a relatively steep part in the first 50 meters before entering the flat land of Black Rocks. The average width of the footprint of the road will be approximately 10 meters (including slope profiling).

Apart from use for goat grazing and hiking, the area is in a fairly natural state. Figure 5.10 shows an impression of the vegetation of the area, which consist mostly of grass land (grass species *Aristida adscensionis* and *Bothriochloa pertusa*) interspersed with both low growing and taller shrubs: haguebush (*Volkameria aculeata*), casha (*Acacia farnesiana*) and black cherry (*Randia aculeata*). The area near the projected harbour is relatively rich in plant species, including a number of rare species and species with conservation importance (see annex 2a). Cana gorda girdlepod (*Mitracarpus polycladus*), which is abundantly present in the area, is an endangered and endemic species to Saba. Several important fauna species are present in the area such as 2 species of iguana and Red bellied racer snake (*Alsophis rufiventris*). See figure 5.10 for an impression of the vegetation at section 4.

Figure 5.10: Impression of section 4. Top left: area where west part of section 4 will be located. Top right: area where east part of section 4 will be located with large shrubs such as haguebush (*Volkameria aculeata*). Mid left: casha (*Acacia farnesiana*). Mid right: small clusters of manchineel trees (*Hippomane mancinella*). Bottom left: haguebush (*Volkameria aculeata*). Bottom right: cana gorda girdlepod *(Mitracarpus polycladus)*

Near the footprint, approximately 10-20 meters southward and eastward, small clusters of manchineel trees are present (see figure 5.11)

Figure 5.11: Manchineel forest : drone image and images within the stand (taken from SCF Ecological survey).

Unmitigated impacts

The unmitigated impact of the environmental and ecological losses in the footprint area of the access road are assessed as “significant”. Although there are no specimens of protected species in the footprint and only two tall trees are very close to the footprint, the footprint area is relatively large (more than 20.000 m2 of which approximately 7.000 m2 vegetated) and harbors important flora and fauna species. The impacts are irreversible to a large extent. See also table 5.1 for a brief evaluation on unmitigated and mitigated impacts.

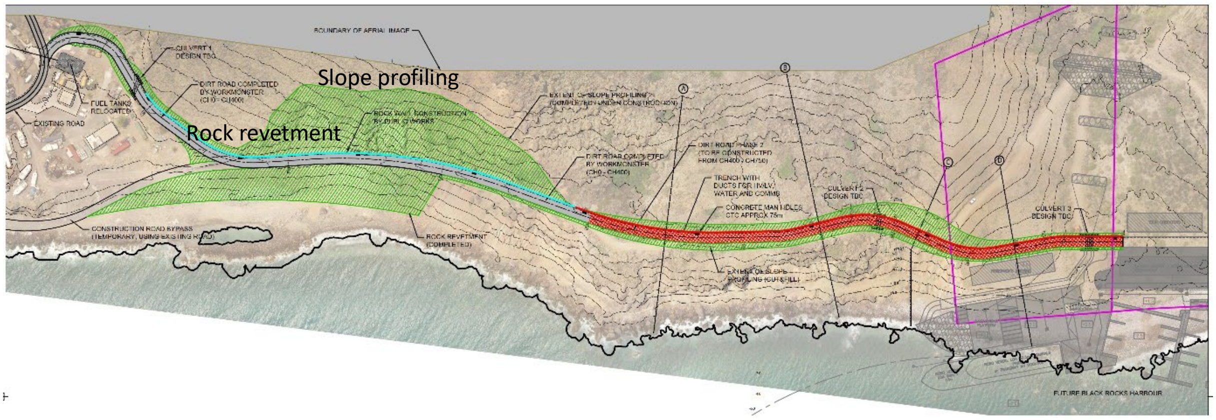


Figure 5.12: Total footprint of access road (green areas total a surface of 20.000m2, of which 7.000 m2 is vegetated)

Impact mitigation

As long as cutting of trees can be avoided, **<u>trees that are near the footprint</u>** will be saved.
Trees that are actually in the footprint area will be **<u>excavated and replanted</u>** near the road (chance of of survival is not 100%).
A **<u>small water catchment area</u>** north of section 3 **<u>will be left intact</u>**.

After profiling of the hill slopes and **<u>stabilizing</u>** these parts, **<u>vegetation will be re-established</u>** in these areas. This can be very challenging because of the steepness of the slopes, the relatively high velocity of runoff water and the sensitivity for erosion. For the success of revegetation, erosion control and goat control are essential. In very steep areas cellular or wire mesh confinement techniques may be required in order to provide for suitable top soil (annex 12). This aspect of revegetation is further elaborated in chapter 6.

Table 5.1 presents a brief evaluation on unmitigated and mitigated impacts in the footprint. Mitigated impact is qualified as "significant". A substantial natural area will be irreversibly lost in the footprint and revegetation towards a diverse plant community takes much time and can only occur in part of the footprint.

Table 5.1: Impact evaluation summary road construction (qualitative evaluation)

Footprint area*	Very large, more than 20.000m2 of which 7.000 m2 vegetated
Important nature elements in/ near footprint	Footprint in Important Bird Area. Section 1 and 2: partly degraded and eroded area; relatively low species diversity. Section 3 and 4: grassland, shrub land and 3 manchineel trees. Section 3 and 4 more biodiverse than section 1 and 2.
Protected species, species of conservation importance in/near footprint	Section 4: Presence of rare plant species and plant species of conservation importance such as Cana gorda girdlepod (*Mitracarpus polycladus*). Fauna of conservation importance: 2 endangered iguana species (1 critically endangered) and red bellied racer snake (vulnerable). likely to be present See also annex 2a
Conclusion unmitigated impact **	Significant
Reversibility	Partly irreversible
Impact mitigation/compensation	Avoid cutting trees, replant trees, stabilizing of slopes with anchors and steel mesh, use of natural fibre matting. In very steep areas cellular or wire mesh confinement techniques may be required. Revegetate profiled slopes with local species, preferably rare, endemic and endangered species
Effectivity impact mitigation/compensation	Revegetation can be effective (in parts of footprint), however species diversity will be poor in the initial phases. Tree relocation may be less effective because survival is uncertain
Conclusion mitigated impact **	Significant

* Small: 0-1.000 m2; medium: 1.000-5.000m2; large: >5.000m2; very large: >10.000m2

** Severe, possibly severe, significant, moderate, low, insignificant, positive

5.2 Footprint of gabion weirs

Figure 5.13 shows the footprint area of the series of gabion weirs north of the harbor, used for upstream water management. The total footprint area of the 11 gabion weirs is approximately 380 m2. Depending on effectiveness during periods of intense rainfall, an additional 7 weirs may be required downstream with a total footprint area of approximately 235 m2. The total footprint of all 18 weirs (worst-case) is approximately 615 m2. The surface of temporary waterbodies upstream of the weirs are not considered footprint since these do not have to be excavated. Besides the total footprint area of all weirs, also a path for the workforce towards the construction areas of the weirs will be impacted. The path towards the highest weir from the north side of the harbor footprint is roughly 450 m.

The construction of the weirs takes place in an area with grassland, shrubs and interspersed trees. A separate assessment for terrestrial nature values has been carried out by the Saba Conservation Foundation. This assessment demonstrates that the area of the gutter is relatively rich in plant species, including a number of rare species and species with conservation importance. Cana gorda girdlepod (*Mitracarpus polycladus*), which is abundantly present in the area, is an endangered and endemic species to Saba. Despite grazing by goats (Rojer, 1997, Mulder 2017, Meesters et al., 2019), the area is in a fair natural state.

There are 14 trees with CBH >50 cm and two more trees with CBH 30 cm-50 cm within the area where the weirs will be built. The tree species found here are: *Acacia farnesiana* (casha), *Ficus citrifolia* (ficus), *Guapira fragrans* (loblolly) and *Capparis indica* (quadrella).
Several important fauna species are present in the area such as 2 endangered species of iguana (1 critically endangered) and the red bellied racer snake (*Alsophis rufiventris*). Approximately 10 protected bat species live in the area. A colony of approximately 100 pairs of red-billed tropic bird is present a few hundred meters northwest of the proposed weirs. In this area also the protected Audubon shearwater (*Puffinus lherminieri*, Annex II species) is breeding (annex 2a). Both bird species are so-called flagship species in Dutch Caribbean nature policy.

Figure 5.14 presents pictures of some nature elements, mainly trees, which are in the area where the weirs will be built. The weirs will be positioned in such a way that no trees need to be removed.

Figure 5.13: Footprint of landside part of harbor and weirs for storm water management

Figure 5.14: a. Dense vegetation in Compagnie's Gutter; b. tree that needs to be worked around (species unidentified); c. Trees that need to be worked around (left arrow) and shrub vegetation with small trees in the gut (right arrow)

Unmitigated impacts

The impact of the environmental and ecological losses in the footprint area of the weirs are assessed as "significant". The footprint area, which is located in an Important Bird Area (IBA) is small (615 m2 in total) and it is possible to work around the mature trees. Also, the workforce will daily travel along a path towards the construction areas of the weirs. This will impact the vegetation by trampling the vegetation on the path.

Besides goat grazing and hiking, this area is still in a fair natural state and harbors important flora and fauna species. Furthermore, the proposed weirs will be constructed in a hydrologically important gutter (see also chapter 4).
Impacts from sedimentation are assessed in chapter 6.
Impacts from noise and presence of workforce are assessed in chapter 7.

Mitigating measures and mitigated impact

Effort will be made to **save all trees that are in and near the footprint area**.
Trees that cannot be worked around will be **excavated and replanted** near the weirs.
In order to prevent trampling of rare vegetation by the workforce a **detailed vegetation survey of the path** has to be executed by a vegetation expert. All observed individual plants of rare species have to be marked for protection or replanted outside the path. Best method to mitigate to be determined by the vegetation expert

Table 5.2 presents a brief evaluation on unmitigated and mitigated impacts in the footprint. Mitigated impact is qualified as “low”.
It must be noted here that the presence of the gabion weirs may also have a positive impact on surrounding vegetation. The series of gabion weirs will slow down the water flow. Water will infiltrate and become available as groundwater for longer periods in the lower areas. (paragraph 7.5).

Table 5.2: Impact evaluation summary construction of weirs (qualitative evaluation)

Footprint area *	Small, 615 m2 (footprint weirs, all vegetated) and 450 m (path workforce 1 m width)
Important nature elements in/near footprint	Footprint in Important Bird Area. Important gutter with associated vegetation located in footprint. Grass land with dense shrub vegetation and several large trees with network of roots (essential to bind the poorly consolidated soil); grazing by goats
Protected species, species of conservation importance in/near footprint	Presence of rare plant species (32 species) and plant species of conservation importance such as Cana gorda girdlepod (*Mitracarpus polycladus*). Fauna of conservation importance: 2 endangered iguana species (1 critically endangered); red bellied racer snake (vulnerable); 10 species of bats. Colony of red-billed tropic bird (flagship species) and presence of Audubon shearwater (flagship species, Annex II) northwest of weirs. See also annex 2a.
Conclusion unmitigated impact **	Significant
Reversibility	Mostly irreversible in footprint of weirs
Impact mitigation/compensation	Avoid cutting trees, replant trees
Effectivity impact mitigation/compensation	Tree relocation may be less effective because tree survival is uncertain
Conclusion mitigated impact **	Moderate

* Small: 0-1.000 m2; medium: 1.000-5.000m2; large: >5.000m2; very large: >10.000m^2
** Severe, possibly severe, significant, moderate, low, insignificant, positive

5.3 Footprint landside part of harbor

The total area occupied by the landside infrastructure and the buildings of the harbor comprises approximately 1,4 ha. Of this area 9000m^2 is vegetated and 5000m2 is a natural beach, which is sparsely vegetated with a transitional beach vegetation).

The area is part of an Important Bird Area. It is mainly vegetated with grass and shrubs (low growing as well as tall shrubs) and a small number of manchineel trees. Approximately 40% of the area is a natural cobble beach with sparse vegetation.
An assessment for terrestrial nature values has been carried out in this area (see annex 2a). The same species occur as described in paragraph 5.2. Approximately 200 meters north-eastward of the harbor area a manchineel forest is located.
Despite grazing by goats (Rojer, 1997, Mulder 2017, Meesters et al, 2019), the area is in a fair natural state.

Figure 5.15 gives an overview of the nature elements present in the footprint of the harbor area, that will be impacted or need to be removed.

Figure 5.15: Current situation in footprint future harbor Top left: view from west side, with indication of footprint of harbor area. Top right: Lower parts of gutter, which will lose its hydrological function in the future. Bottom left: view from east side (in footprint). Bottom right: natural cobble beach

Unmitigated impact

Unmitigated impact is considered “possibly severe”, because of the location of the project in an Important Bird Area, and the large size of the area, which is still relatively intact. The area harbors important flora and fauna species (see paragraph 5.2, table 5.3 and annex 2a). Furthermore, the proposed harbor will be constructed in the lower part of a hydrologically important gutter, that will lose its ecological function (see chapter 4). The ecological impact in the footprint area is largely irreversible.
Impacts from sedimentation are assessed in chapter 6.

Mitigating measures and mitigated impact

In the harbor area **vegetation will be left intact** where possible and **trees** of the same species as those that occur locally, **will be planted in the developed area**.

Table 5.3 presents a brief evaluation on unmitigated and mitigated impacts in the footprint. Mitigated impact is qualified as “significant”. Effectivity of impact mitigation is low (mitigation can take place in relatively small part of the footprint and most of the footprint will be lost irreversibly.

Table 5.3: Impact evaluation summary footprint harbor area (qualitative evaluation)

Footprint area *	Very large: 1,4 hectares, of which 9000m2 vegetated and 5000m2 natural beach which is sparsely vegetated, (transitional beach vegetation)
Important nature elements in/near footprint	Area is part of Important Bird Area (AN006). Area in fair natural state. Grass land and shrub vegetation; moderate species diversity, grazing by goats. Important gutter in footprint. Manchineel forest at 200 m distance.
Protected, threatened species in/near footprint	Presence of rare plant species (32 species) and plant species of conservation importance such as Cana gorda girdlepod (*Mitracarpus polycladus*). Fauna of conservation importance likely to be present: 2 endangered iguana species (1 critically endangered); red bellied racer snake (vulnerable); 10 species of bats. Colony of red-billed tropic bird (flagship species) and presence of Audubon shearwater (flagship species, Annex II) northwest of weirs. See also annex 2a.
Conclusion unmitigated impact **	Possibly severe
Reversibility	Largely irreversible
Impact mitigation/compensation	Avoid cutting of trees, revegetation, planting of native trees where possible
Effectivity impact mitigation/compensation	Low, impact mitigation can take place in relatively small part of the footprint
Conclusion mitigated impact **	Significant

* Small: 0-1.000 m2; medium: 1.000-5.000m2; large: >5.000m2; very large: >10.000m2

** Severe, possibly severe, significant, moderate, low, insignificant, positive

5.4 Footprint marine infrastructure

The construction of the breakwater will result in the covering of a part of the seafloor by the structure itself (see chapter 3). The footprint area will depend on the method chosen and will -in the worst-case situation- be approximately 13.000 m2. This is when the base case of the berm breakwater is chosen (40 meters wide at bottom). In case of construction of the caisson structure, the footprint area will be 5.000 m2, and in case of the cofferdam 4.000 m2. The internal basin of the harbor (15.000 m2) and the shipping lane (approximately 5.000 m2) that need to be dredged and made free of rocks are also part of the footprint area. The total footprint amounts to 24.000 - 33.000 m2 (2,4 ha – 3,3 ha) depending on the type of breakwater.

To this footprint we add a high-risk zone where working is intense, anchoring will occur and where dredging barges (with spuds) will be present. Larger sediment particles (63 µm-200 µm) that will not be transported in the plume will deposit in this area. These particles, that are available in the marine sediments abundantly (see annex 4), have a vertical velocity in water of 1.3 cm/sec[1]. With assumed local currents (see chapter 4) ranging from 0,06 m/s to 0,15 m/s these particles will travel approximately 50-100 meters from the source.
Therefore, the high-risk zone is defined at a distance of 100 meters from the actual footprint in the western parts of the harbor (because of predominant currents to the west). At the south part and east part of the harbor we assume a significantly smaller risk area of 25 meters because of the presence of less barges and other vessels, the incidental nature of current reversals, and the possibility to take measures in the event of a current reversal (see further in this paragraph). In this 25-meter zone a certain risk for density driven sediment transport from core of the breakwater, during placement, is assumed.
The footprint including the high-risk zone is illustrated in figures 5.16 and 5.17. This concerns the worst-case footprint, i.e. by the berm breakwater.

[1] The representative diameter for this class is 115 µm

The total area of the footprint and the high-risk zone is 90.000m2 (9 ha, worst case situation, based on berm breakwater).

Figure 5.16 shows that the actual footprint of the breakwater is mainly in an area with large boulders. In this footprint area scattered rocks are present with low densities of benthic growth: mainly hard corals, sponges, sea anemones and tube worms. The mean coral cover in this area is approximately 1,6% (see chapter 4). The high-risk zone also overlaps 3 patch reefs, on the west side, the east side and the south side of the breakwater.
In case of construction of the larger 214m pier (indicated with green colour in figure 5.16), in combination with the choice for a berm breakwater, which is the base case, construction will take place at the very edge of the patch reef, situated just south of the construction, see figure 5.16. The footprint of a cofferdam construction would result in a significantly lower impact, since the cofferdam footprint is 25 meters less wide (see chapter 3).

Figure 5.17 shows the protected corals (colonies) that are within the footprint including the high-risk zone. In this area 72 colonies of *Acropora palmata* were found, 26 colonies of *Montastraea annularis*, and 100 colonies of *Montastraea faveolata* (see also table 5.4 and annex 2b). *Acropora cervicornis* was not observed in the high-risk zone. These numbers correspond to the worst-case situation (choice of a berm breakwater). If the cofferdam structure would be chosen instead of the berm breakwater, the footprint would be significantly narrower leading to the loss of less colonies, especially of the Orbicella and Acropora genus. In that case, 102 less colonies of protected species will be lost in the footprint and high-risk area and need to be removed to another location (see table 5.4). In case of the caisson structure this will be 46 less corals in the footprint that need to be removed.
These numbers are based on counts of 75% of the area within the high-risk zone. Final counts will be made during relocation of the protected corals.

Besides these protected corals, also an unknown number (possibly hundreds) of colonies of non-protected species (mainly from genera Millepora, Siderastrea, Madracis, Porites and brain corals, possibly hundreds) and an unknown number of sponges and macro invertebrates such as sea urchins and sea cucumbers are in the footprint and high-risk zone. If no mitigating measures will be executed, the levelling and covering of the seafloor, and other construction activities (e.g. anchoring, dredging) will lead to the almost complete loss of this benthic fauna.

Other reefs down current may also experience impacts from the loss of (protected and non-protected) corals in this area, since the colonies growing in the area are representing the gene pool responsible for successful reproduction on other reefs (e.g. Tent)

Non-benthic fauna is expected to leave the area during construction. Several of these species may return after construction.

Table 5.4: Number of colonies of protected species[1] in footprint area and high-risk zone which need to be relocated (different breakwater types)

Species	# of colonies (berm 40m wide)	# of colonies (cofferdam 15m wide)	# of colonies (caisson 20m wide)
Acropora palmata	72	57	
Acropora cervicornis	0	0	
Orbicella annularis	26	22	
Orbicella faveolata	100	36	
Total count (75% of area)	198	115	
Total in area (extrapolated)	246	144	200

[1] Annex II species according to the SPAW Protocol: *Acropora palmata*, *Acropora cervicornis* , *Montastraea annularis*, *Montastraea faveolata*

* For the caisson structure no counts were made; this number was estimated, based on the intermediate footprint of the caisson structure (20m width)

A remark that needs to be made with respect to the footprint area is that, during the construction of a caisson breakwater or a cofferdam, no density currents of heavy, sediment-loaded water are expected to run in lateral directions from the main axis of the breakwater, as this may be the case during construction of the berm breakwater. The filling with aggregates of the caissons and cofferdam structure does not take place in open water but in semi closed spaces.

Unmitigated impact

The unmitigated impact from activities in the footprint and high-risk area on all marine fauna is classified as “severe”, because of the abundance of corals to which “total protection and recovery” apply (SPAW Protocol article 11 clause 1 sub b).

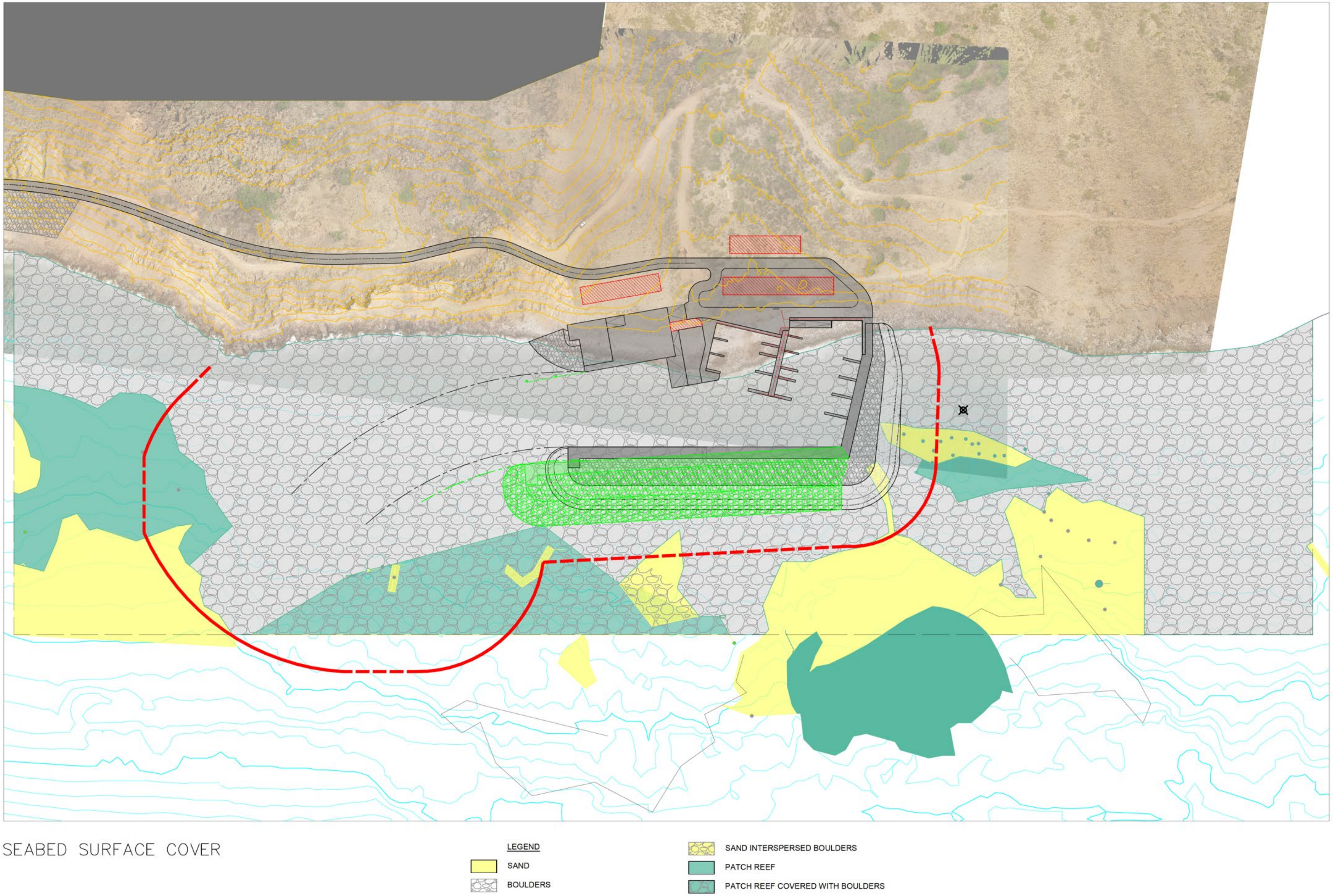


Figure 5.16: Footprint including high-risk zone of harbor in relationship to seafloor cover and patch reefs

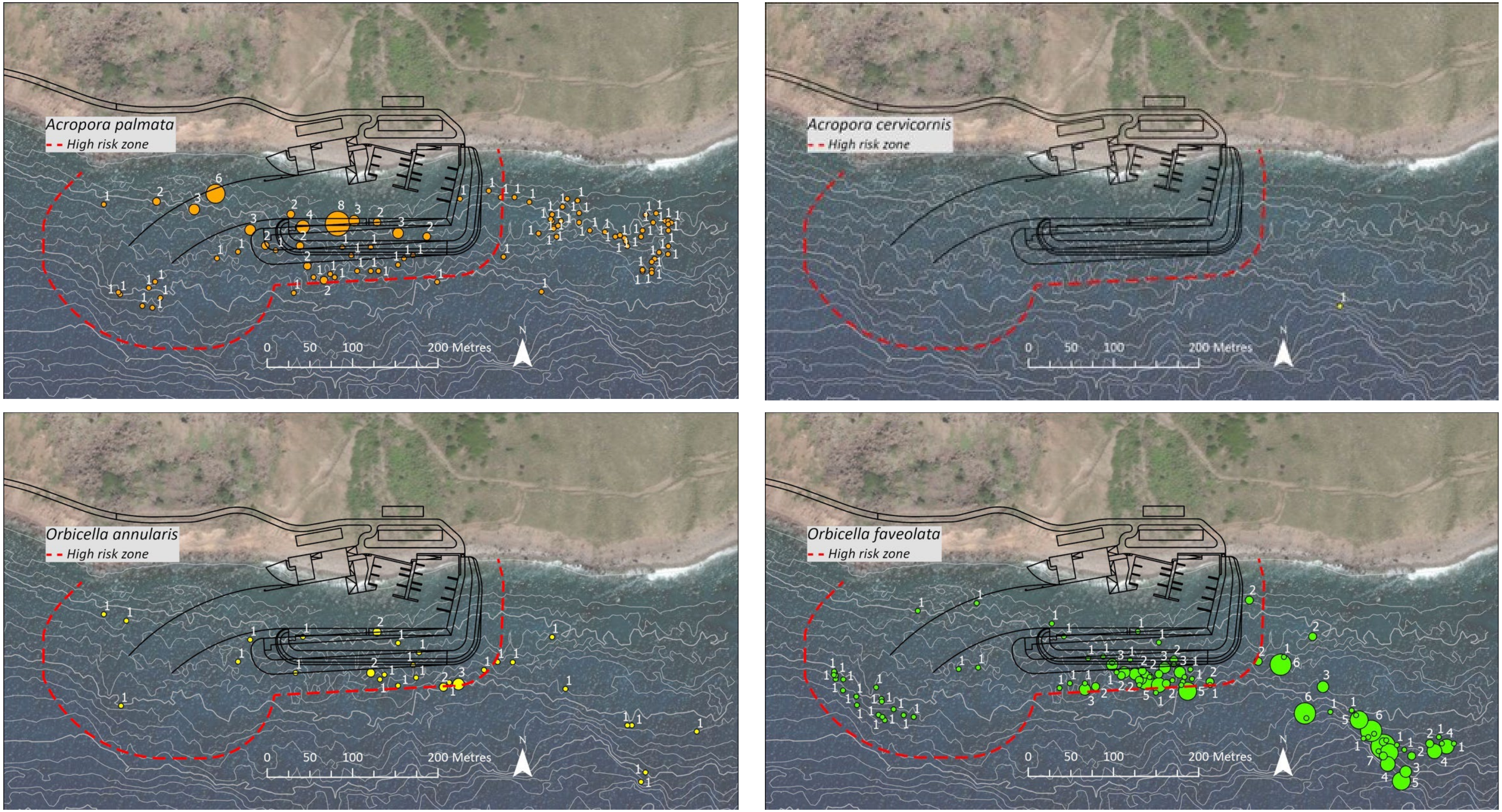


Figure 5.17 Distribution of protected and important (vulnerable) coral colonies

Mitigating measures and mitigated impact

Prior to the start of construction, **all protected corals will be relocated** from the footprint area, and the high-risk zone[1] to an area where survival for these species is considered adequate. To assess which area is the most favorable area for relocation, a pilot project was carried out by SCF. The report of this relocation trial is included in Annex 2e). In this project coral fragments and colonies are being held in a nursery and subsequently planted out in 2 different areas (Ladder Bay and Hole in the Corner). From the trial it was concluded that 'Hole in the Corner' is the most suitable area for the relocation of the corals.

Success rates for relocation of coral vary from species to species. According to a recent review (Bostrom-Einarsson, 2020), mean survival rates for a range of species is 64% in case of direct outplanting to 66% in case of outplanting from an intermediary nursery. In the Caribbean, long term survival rates for *Acropora palmata* can be particularly high, as demonstrated in Belize (89-99% after 6 years, Carne, 2016), especially in case of outplanting from an intermediate nursery. These high success rates are not self-evident however; Omori (2011) found much lower rates (3% after 12 years). Success rates seem to depend strongly on the long-term quality of the new environment.

For *Orbicella* species, survival rates after direct transplantation can be as high as 80 percent (Monty, 2006). This figure however is based on relatively little data and should be used with caution. Another possible indication is the survival rate of a number of genera growing in spherical shapes: Porites, Orbicella, Montastrea, Siderastrea, Diploria, Stephanocoenia, Solenastrea, Meandrina and Dichocoeania, which was found to be 71% (direct transplantation, Bostrom-Einarsson, 2020).
See annex 9 for a brief literature review in this matter.

According to Saba Conservation Foundation, the best timing for relocation is November-December, when water temperatures are cooling down.
Assuming a conservative 65% survival of colonies after relocation, the number of colonies of protected coral species not surviving after relocation would be 86 in the base case.

Corals and other benthic fauna *without* protection status will not be transplanted, and will be lost in the footprint and high-risk area. The coral species to which this applies are the naturally occurring species at the depth of the footprint and high-risk area, 0-8 meters, such as *Millepora complanata* (fire coral), *Madracis mirabilis, Siderastrea siderea, Dendrogyra cylindrus* (pillar coral), *Porites astreoides* (mustard hill coral) and brain corals. For these corals, compensation could take place in the form of **enhanced recruitment and settlement of corals**.
Innovative methods of enhanced laboratory coral hatching and recruiting may be considered, such as a Dutch method developed by CSIRO, Delft University of Technology and partners from the private sector: Reefguard/Coral Engine. The Saba Conservation Foundation and the Saba Coral Nursery Project would be important partners in such a project. In the coral nursery near Ladder Bay, managed by these organizations, hundreds of specimens of *Acropora palmata, Acropora cervicornis, Dendrogyra cylindrus, Montastraea faveolata* and brain corals are being grown[2].

If the **armour rock** on the seaside of the new breakwater is carefully selected, it may form a **suitable substrate** for the coral fragments to grow to maturity, as well as for natural as for enhanced coral-recruitment. Tests in Japan have indicated that pre-treated blocks with high surface roughness promote settling of coral larvae and growth of juvenile corals (socalled Ecoblocks, PIANC, 2010).

[1] See chapter 7 for other reasons for relocation, such as altered currents and wave action
[2] The Saba Coral Nursery Project is willing to cooperate in this project (Dr. J. Nahr, volunteer)

Although the perspectives for the new techniques and construction materials seem good, uncertainties remain with respect to the suitability of the new environment for recolonization of corals and other marine benthos. *Acropora palmata* is a fast-growing species, but for most other species, settlement and regrowth of coral to pre-impacted states may take decades.

Other possible compensation measures are:

- Creation of artificial reefs, in line with "Diadema City" (see chapter 9) at Gary's Pond. Diadema City provides shelter for at least 2000 specimens of Diadema antillarum, a large quantity of fish with high fish diversity, and very good conditions for coral recruitment
- A contribution to the planned establishment of the "Saba Sea Lab" for coral reef research and restoration-

In conclusion, mitigation measures can prevent a part of the ecological damage. Nonetheless, mitigated impacts are considered "significant", because of the partial survival of the replanted colonies of protected species (expected 65-70%), the significant initial loss of suitable habitat for shallow water corals and other marine species, and uncertainties around re-establishment of these species.

Table 5.5: Impact evaluation summary footprint marine infrastructure (qualitative evaluation)

Footprint area small, medium, large (*)	Large (9 ha, including high-risk zone)
Important nature elements in/near footprint	246 colonies of protected corals (base case), unknown quantities of other coral species and marine benthos
Protected, threatened species in/near footprint	Yes
Conclusion unmitigated impact	Severe
Reversibility	Partly irreversible
Impact mitigation/compensation	Relocation of protected corals; enhanced settlement of other (juvenile) corals; armor rock for breakwater suitable for coral settlement
Effectivity impact mitigation/compensation	Expected survival of protected corals approximately 65-70%; re-establishment of other coral species is uncertain and will take a significant amount of time
Conclusion mitigated impact	Significant

* Small: 0-1000 m2; medium: 1000-5000m2; large: 5000-10.000m2; very large: >10.000m2

6 Impacts from sediment load

In the following paragraphs impacts from suspended solids in the water column and sediment deposition will be described. Impact assessment has been carried out with both qualitative methods (for terrestrial infrastructure) and quantitative methods (for marine construction and dredging).
In the qualitative assessment we will use the following classification of impacts: “severe”, “possibly severe”, “significant”, “moderate” “low” and “insignificant”. This will be done for both unmitigated and mitigated impacts.

6.1 Sensitivity of coral species to fine sediments

Figure 6.1 indicates the general relationship between the intensity and duration of a stress event (such as turbidity, light reduction and sedimentation) and the risk of sublethal and lethal effects on corals. Sublethal effects can include reduced growth, lower calcification rates, reduced productivity, bleaching, increased susceptibility to diseases, physical damage to coral tissue and reef structures (breaking, abrasion), and reduced regeneration from tissue damage (Erftemeijer, 2012).

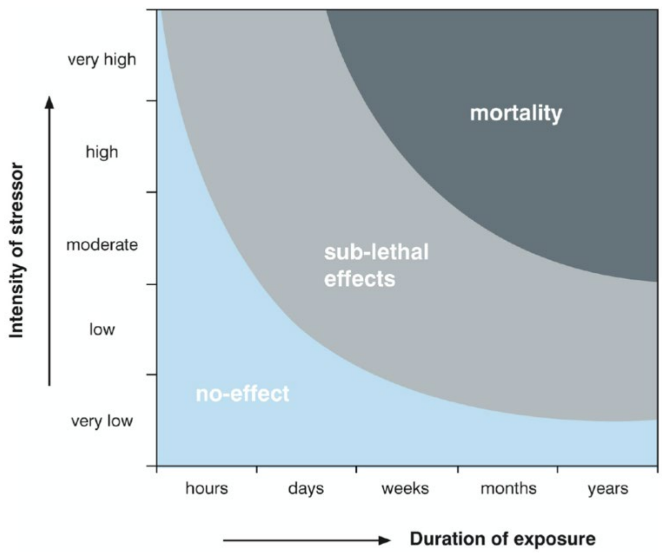


Figure 6.1: General relationship between the magnitude of an increase in turbidity or sedimentation above background levels (vertical axis), how long it lasts (horizontal axis) and the onset of (sub)lethal effects on corals. Actual thresholds will vary by location, sediment properties (e.g. grain-size) and the sensitivity of the coral species (from: Erftemeijer et al, 2012).

Light reduction (as a result of high turbidity) is probably the most important of all sediment-related effects of dredging on corals, resulting in a decline in photosynthetic productivity. Such a decrease causes a subsequent drop in the nutrition, growth, reproduction, calcification rate and depth distribution of corals and may result in starvation of some coral species (Erftemeijer et al, 2012).

High levels of sedimentation (deposition) can cause smothering and burial of coral polyps, shading[1] and tissue necrosis. Mud and silt-sized sediments have a more adverse impact than sand because they are more cohesive and bind nutrients better than sand. Therefore, a more active bacterial community is likely to develop in silt-laden mucus sheets, causing damage to the corals (PIANC, 2010). Fine sediments can also negatively impact coral recruiting (Perez, 2014, Jokiel et al., 2014).

[1] Symbiotic algae in corals or zooxanthellae, on which corals depend, need light for photosynthesis

Sediments rich in organic matter, especially from land-based sources, cause tissue degradation at rates 6 times faster than sediments poor in organic matter. This effect is also related to growth of bacteria and the development of anoxic conditions in coral mucus (Weber, 2012).

Table 6.1 lists the response of corals to increasing levels and durations of sedimentation and turbidity.

Table 6.1: Schematic cause-effect pathway for the response of corals and coral communities to sedimentation and turbidity (In PIANC, 2010; adapted from Gilmour et al., 2006)

Increasing Level and Duration of Stress

	Sedimentation	Turbidity
STRESS		
Photo-physiological stress	• Reduced photosynthetic efficiency of zooxanthellae and autotrophic nutrition to coral	• Reduced photosynthetic efficiency of zooxanthellae and autotrophic nutrition to coral
Changes in polyp activity	• Extrusion of mesenterial filaments following severe stress • Increased ciliary or polyp activity, and tissue expansion in some species to remove sediment	• Extrusion of mesenterial filaments following severe stress • Increased ciliary or polyp activity to feed
Mucus production	• Mucus production or sheeting to remove sediment	• Evidence of mucus production
SEVERE STRESS		
Sediment accumulation	• Accumulation of sediment on tissue of susceptible growth forms due to failure of mechanisms of rejection	
Change in coral colour	• Change in coral colour arising from changes in the density of zooxanthellae and photosynthetic pigments • Paling of coral due to partial bleaching	• Change in coral colour arising from changes in the density of zooxanthellae and photosynthetic pigments • Darkening of coral in response to reduced light due to photoacclimation
Bleaching	• Considerable whitening of corals due to the expulsion of a large proportion of zooxanthellae from the colony	• Considerable whitening of corals due to the expulsion of a large proportion of zooxanthellae from the colony
PARTIAL MORTALITY		
	• Injury to coral tissue, loss of polyps and partial mortality of the colony • Decrease in (live) coral cover	• Injury to coral tissue, loss of polyps and partial mortality of the colony • Decrease in (live) coral cover
MORTALITY		
	• Mortality of small-sized colonies and partial mortality of large corals • Mortality of susceptible species and size classes. • Decreased density, diversity and coral cover • Changes in community structure • Widespread mortality of corals • Major decreases in density, diversity and coral cover • Dramatic changes in community structure, and shifts towards the dominance of non-coral species, such as sponges and algae	• Mortality of susceptible species and size classes. • Decreased density, diversity and coral cover • Changes in community structure • Wide-spread mortality of corals • Major decreases in density, diversity and coral cover • Dramatic changes in community structure, and shifts towards the dominance of non-coral species, such as sponges and algae

In table 6.2 the sensitivity to high turbidity and sedimentation of several coral species occurring in the Black Rocks area are summarized.

Table 6.2: Sensitivity of several species occurring in the area for turbidity, light reduction and sedimentation

Species	**Sensitivity for turbidity and light reduction**	**Sensitivity for sedimentation**	**Sensitive/ tolerant/ intermediate**	**Source**
Acropora cervicornis	Species most sensitive to light reduction	Thin, stick forms such as *Acropora cervicornis* are ideally suited passive sediment shedders	Intermediate, but sensitive to light reduction	Erftemeijer, 2012; Rogers, 1979 and 1990
Acropora palmata	Branching corals (Florida): sensitive to light reduction (need 60% of SI)	Ineffective sediment remover, depends strongly on passive removal (e.g. waves)	Sensitive	Jaap and Hallock 1991; Rogers 1983; Bak and Elgershuizen 1976
Montastraea (Orbicella) annularis	1–10 mg/l TSS for 6 weeks had minor effect on feeding response. Star and brain corals (Florida) can sustain at 20% of SI	Tolerance to sedimentation described as ’intermediate’ Tolerant for at least 38 days for 200 mg/cm/day	Intermediate	Szmant-Froelich et al. 1981; Abdel-Salam and Porter 1988; Rogers 1979 Jaap and Hallock 1991
Montastraea (Orbicella) faveolata	No specific data; star and brain corals (Florida) can sustain at 20% of SI	No specific data	Unknown	
Montastraea (Orbicella) cavernosa	Severe light shading for 5 weeks: no visible effects	Sediment resistant	Tolerant	Bak and Elgershuizen 1976; Rogers 1979
Porites astreoides	No data for longer periods	Maintenance of extension rates (growth) in wide range of sediment conditions over 5y	Tolerant	Torres and Morelock 2002
Diploria strigosa		Removes sediments efficiently	Tolerant	Kolehmainen 1973b (in Loya, 1976)
Siderastrea siderea	Partial bleaching after 5 weeks of severe light reduction, partial recovery in 6–8 weeks	Maintenance of extension rates (growth) in wide range of sediment conditions over 5y	Tolerant	Rogers 1979; Torres and Morelock 2002
Millepora alcicornis	No data	(4 mg/m2/day) Tolerance to sedimentation described as ’intermediate’	Intermediate	McClanahan and Obura 1997
Gorgonians (seawhips)	Among most tolerant species to dredging induced turbidity (Marszalek 1981); Soft corals relatively sensitive to turbidity (Erftemeijer et al. 2012)	Among most tolerant species to sediment loading	Intermediate	Marszalek 1981 Erftemeijer et al. 2012

From the overview it can be concluded that especially Acropora species are sensitive to light reduction from sediment related changes. Other species that are present in the area of Black Rocks can be characterized as “intermediate” or “tolerant”.

6.2 Thresholds for turbidity and sedimentation

Uncertainties and precautionary approach

Setting meaningful threshold values for turbidity and sedimentation, guaranteeing safe conditions for sensitive areas and species is a difficult challenge. Even after decades of research, there is no full understanding of in situ responses of many coral species to sediment disturbance (Jones et al., 2017, Erftemeijer, 2012). Until such relationships are determined, there will always be substantial uncertainty associated with impact prediction for dredging near coral reefs (Jones et al., 2017).

Because of the uncertainties involved, the definition of local standards in this EIA must be seen as a broad guideline that can help with the decision making. It is not meant as a final set of thresholds, nor as a guideline for permitting. For final threshold development and permitting, additional research into background suspended solids concentrations (SSC) and background sediment deposition needed. SSCs and related turbidity are naturally highly variable, both spatially and temporally, and influenced by a wide range of factors, such as waves, currents and bed type. Therefore, data-acquisition needs to span a relatively long sample period (typically months, Jones, 2015). When this data is available it can be used to quantify the intensity, duration and frequency of natural background levels and use these to define certain threshold limits during construction and dredging. This method is described in detail in (McArthur, C. et al, 2002) and is based on the principle goal of preventing significantly greater exposure beyond that to which the coral community is presently adapted.

In this EIA we propose to use conservative preliminary thresholds for turbidity and sedimentation. Additional reasons for a cautionary approach are the following:

- The construction of the new harbor is in a relatively pristine area, where stress factors are not common for longer periods (except for storms and hurricanes);
- There is a lack of background data for Saba (e.g. SSC and sedimentation) during “normal” and high turbidity episodes (e.g. hurricanes);
- The duration of the construction and dredging works is relatively long (at least 18 months);
- Vulnerable patch reefs and protected corals are located near the construction area (some of them < 100 meters);
- Hydraulic (3D) models have limited spatial resolution, and are less suitable for predicting impacts at distances less than 150-200 meters from the source.

Should additional monitoring become available, in addition to and validating the TSS monitoring recently done (Annex 14), the alternative ‘McArthur’ method can be considered to define more precise threshold and intensity guidelines. This method is based on defining several threshold levels and linking these with a maximum duration and frequency rather than defining a single fixed TSS limit. The TSS is monitored continuously during construction (dredging/disposal) and compared against the set threshold and intensity levels to inform whether activities can continue or should be paused.

Types of thresholds

According to Jones et al. (2017), multiple thresholds are needed, i.e. for SSC, light attenuation and sediment deposition. Preliminary thresholds for SSC and sediment deposition (sedimentation) were defined for this EIA (see next sections).
For light attenuation, no separate preliminary threshold was developed, because at this stage such a threshold cannot be tested (insufficient data with respect to the typically local relationship between SSC and light attenuation).

PIANC-thresholds

The World Association for Waterborne Transport Infrastructure (PIANC) presents a well-validated and widely used set of tolerance limits, developed in Singapore, which also includes duration of elevated TSS concentrations (PIANC, 2010). The case presented by PIANC however is reflective of the relatively high background turbidity and high sedimentation rates in Singapore. SSC and sediment deposition at the Singapore reefs are 10-14 mg/l and 5-20 mg cm^{-2} day^{-1}, respectively (Van Maren et al. (2014)[1].

The PIANC thresholds are selected as a base for the definition of the preliminary thresholds for the EIA, and are amended to better reflect the Saba situation, which is a Marine Park with relatively clear waters (see also chapter 4).

Table 6.3: PIANC threshold values for dredging in Singapore (PIANC report, 2010). Background SSC 10-14 mg/l and background sedimentation rate 5-20 mg cm^{-2} day^{-1} (Van Maren et al., 2014).

Severity	SSC as excess value	Sedimentation as excess value
No impact	> 5 mg/l for less than 1% of time	< 5 mg cm^{-2} day^{-1}
Slight impact	> 5 mg/l for less than 10% of time > 10 mg/l for less than 1% of time	< 10 mg cm^{-2} day^{-1}
Minor impact	> 5 mg/l for less than 20% of time > 10 mg/l for less than 5% of time	< 20 mg cm^{-2} day^{-1}
Moderate impact	> 10 mg/l for less than 20% of time > 5 mg/l for more than 20% of time	< 50 mg cm^{-2} day^{-1}
Major impact	> 25 mg/l for more than 5% of time > 10 mg/l for more than 20% of time	> 50 mg cm^{-2} day^{-1}

Category description:

No Impact: Changes are significantly below physical detection level and below the reliability of numerical models, so that no change to the quality or functionality of the receptor will occur.

Slight impact: Changes can be resolved by numerical models, but are difficult to detect in the field as they are associated with changes that cause stress, not mortality, to marine ecosystems. Slight impacts may be recoverable once the stress factor has been removed.

Minor impact: Changes can be resolved by numerical models and are likely to be detected in the field as localised mortalities, but to a spatial scale that is unlikely to have any secondary consequences.

Moderate impact: Changes can be resolved by numerical models and are detectable in the field. Moderate impacts are expected to be locally significant.

Major impact: Changes are detectable in the field and are likely to be related to complete habitat loss. Major impacts are likely to have secondary influences on other ecosystems.

Linking thresholds to background values

Background concentrations of TSS and the deposition of sediments for Saba have not been monitored in the past, but has recently been monitored for a period of about 2.5 months. The average TSS was calculated at 25mg/l, with a variation between 0 – 80mg/l. This is based on a generic correlation between FTU and TSS. Until this monitoring is continued for another 3 months and validation of the FTU – TSS correlation has been done with water and sediment sampling, preliminary TSS levels used in this EIA are based on measurements at nearby islands. See Annex 14 with results and recommendations from the TSS monitoring.

The nearest islands where monitoring of TSS and sedimentation has taken place are the US Virgin Islands (USVI) St. John, St. Thomas and St. Croix (NOAA, 2015, Smith et al. 2013). Most monitoring programs took place at the east side of these islands. Although differences exist in coast morphology, morphology of fore reefs, and wave action, in the absence of data, we assume that the average SSC in the coastal waters of south Saba is in the range of the values observed in the coastal waters of

[1] Turbidity is spatially and vertically relatively uniform over the stations investigated (Van Maren et al., 2014).

these islands (4-7 mg/l) and that sedimentation is between approximately 1 and 9 mg cm^{-2} day^{-1} (average 3.4 mg cm^{-2} day^{-1}), see table 6.4.

According to Loya (1976) and Pastorok and Bilyard (1985), a level of deposition of 3 mg cm^{-2} day^{-1} can be regarded as low. Since visibility in the Saban waters is relatively high compared to other Caribbean sites (see chapter 4), the relatively low values of SSC and sedimentation in the USVI are likely to be expected in Saba as well (until further monitoring and validation proves otherwise).

Table 6.4: SSC and sedimentation in the US Virgin Islands (Data from NOAA, 2015 and Smith et al., 2013)

	SSC (m/l)			Sedimentation		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
St. Thomas						
STEER (6 locations)	0.5	4.7	18.6	0.7	3.4	9.0
St. John*						
Lameshur Bay	0.4	6.5	22.0			
Coral Bay	1.0	6.5	22.0			
Fish Bay	0.8	6.8	24.0			
St. Croix*						
Teague Bay	1.0	6.4	28.0			

Average SSC and sedimentation

Rogers (1990) suggested that average SSC at or above 10 mg/l can affect the structure and function of coral reef ecosystems in the Caribbean. Impacts include fewer coral species, less live coral cover, lower growth rates, reduced recruitment and decreased calcification. Turbidity-related light limitation reduces gross photosynthesis. Rogers further reported that sedimentation rates in excess of 10 mg cm^{-2} day^{-1} (average) are deleterious to corals. Nemeth and Sladek Nowlis (2001) provided additional data from the USVI that showed coral bleaching and mortality at sedimentation rates above this threshold.
Although background values for Saba have not been established yet, proposed preliminary threshold values should reflect that effective SSCs and sedimentation rates (background plus project related) do not exceed the critical values mentioned in this paragraph.

Short term SSC (peaks)

Due to the highly variable nature of the turbidity events care needs to be taken when (only) summarizing data over longer time periods (Jones, 2015). During three North West Australian dredging projects average values of turbidity increased by 2–3 fold during dredging, but intensity of turbidity peaks increased by a rate of more than 10. Generated peaks lasted five times longer than during the baseline period, and peaks occurred up to three times more frequently. These peaks are important to control since they can have ecological consequences (Jones 2015).

Background data on the distribution of naturally occurring SSCs (including peaks) on Saba is based on a relatively short measurement period with gives peak values (99% percentile) of about 80mg/l. this is however based on a generic correlation between FTU and TSS and should be validated with actual water/sediment sampling and lab analysis.

During a research program by NOAA in the St. Thomas East End Reserve SSCs have been monitored during 22 months (1 sample per month). Although the frequency of sampling must be regarded as very low[1], the results can be used as an indication (see table 6.5).

Table 6.5: SSC (mg/l) in St. Thomas East End Reserve based on 22 months of data collection on a

[1] High frequency time series data of turbidity measurement over long durations are expensive to implement and relatively rare (Jones et al., 2015)

monthly basis (NOAA, 2015)

	Average	Median	80-percentile	90-percentile
Brenner Bay	8	6	10	14
Cowpet Bay	4	2	5	9
Little St. James	2	2	3	3
Mangrove Lagoon	6	5	10	10
Rotto Cay	4	2	6	10
St. James	3	2	6	7

Preliminary threshold proposal

In order to come to preliminary thresholds that are both realistic and reflect proper caution, for the harbour project in Saba we amend the PIANC-thresholds as follows:

1. Effective average SSCs and sedimentation rates (background and project related) should not exceed the critical values for SSC and deposition of 10 mg/l and 10 mg cm^{-2} day^{-1} respectively[1];
2. Preliminary thresholds for different levels of impact from SSC (80-, 90, 95- and 99 percentile) are 5 times lower than the Singapore (PIANC) case, where background values in Saba are expected to be 2 times lower. These threshold values (see table 6.6 second column) seem conservative when compared to the 80- and 90-percentile values in St. Thomas[2], however, utmost caution should be exercised, since no data are present on the distribution of naturally occurring SSCs (including peaks) on Saba.
3. Proposed preliminary sedimentation thresholds for Saba are 10 times lower than the Singapore (PIANC) case, where background values in Saba are expected to be 2-7 times lower (table 6.3). Since sediment deposition is proportionate to SSC, these values are also considered conservative.

Table 6.6: Proposed preliminary threshold values for construction and dredging in Saba. Assumed background average SSC in Saba is 5-7 mg/l and average background sedimentation rate is 0.7-9 mg cm^{-2} day^{-1} (mean: 3.4 mg cm^{-2} day^{-1})

Severity	SSC as excess value (percentile values)	SSC as excess value (average)	Sedimentation as excess value (average)
No impact	> 1 mg/l for less than 1% of time	< 0.5 mg/l	< 0.5 mg cm^{-2} day^{-1}
Slight impact	> 1 mg/l for less than 10% of time > 2 mg/l for less than 1% of time	< 1.0 mg/l	< 1 mg cm^{-2} day^{-1}
Minor impact	> 1 mg/l for less than 20% of time > 2 mg/l for less than 5% of time	< 1.5 mg/l	< 2 mg cm^{-2} day^{-1}
Moderate impact	> 2 mg/l for less than 20% of time > 1 mg/l for more than 20% of time	< 2.0 mg/l	< 5 mg cm^{-2} day^{-1}
Major impact	> 5 mg/l for more than 5% of time > 2 mg/l for more than 20% of time	> 2.0 mg/l	> 5 mg cm^{-2} day^{-1}

Applicability

The preliminary thresholds will be used for 4 nearby patch reefs, the dive site Giles Quarter/Greer Gut and the location of the “dense patch reefs” east of the project area.

[1] There is a distinct possibility that background values for SSC and deposition are already near the critical values of 10 mg/l and 10 mg cm^{-2} day^{-1}. Such a situation should be evaluated in the development of the final thresholds

[2] The value of 2 mg/l for 20% of the time marks the threshold between “moderate” and “major” impact (table 6.6), which can be compared with the 80-percentile of background values in St. Thomas (table 6.5)

Sensitivity of corals

According to Erftemeijer et al. (2012), most coral species can tolerate SSCs of < 10 mg/l and sedimentation rates of < 10 mg cm^{-2} day^{-1}, with the exception of sensitive species and very sensitive species. As described in chapter 4, the genera occurring most in the patch reefs are: Siderastrea, Orbicella and Porites, along with Millepora and gorgonians. Most of these corals can be characterized as “tolerant” or “intermediate”, with the exception of *Acropora palmata* (“sensitive”, see paragraph 6.1). *Acropora palmata* colonies will be largely relocated from the area (chapter 5). Therefore, the risks involved with the proposed set of preliminary thresholds are expected to be acceptable.

A note on organic matter

Many studies have shown the impact of organic content of sediments on coral sediment clearance and survivorship (Weber et al., 2012; Weber et al., 2006). Organic-rich sediments cause tissue degradation at rates 6 times faster than organic-poor sediments (Weber, 2012). This effect is related to growth of bacteria and the development of anoxic conditions in coral mucus.
Organic matter in the sediments in Black Rocks is very low, in most samples below detection limits., which may be related to the wave-exposed nature of the fore-shore at Black Rocks. Because of this situation, additional risks related to organic matter are of less concern.

Feasibility of thresholds

The question whether the standards are feasible for the project-proponent is relevant. The answer to this question is most likely affirmative, since both the construction and the dredging activities are relatively small compared to activities described in literature. For instance: the dredging project in Saba and the dredging capacities deployed, are 1 to 2 orders of magnitude (10-100 times) smaller than most of the dredging projects studied in literature (e.g. NW Australia, Jones et al., 2016).

Coral spawning

It has been recognized since the early 1990s that dredging activities may impact important events such as mass coral spawning, through the generation of suspended sediments. Especially (external) fertilization of coral gametes, larval development and larval settlement appear to be critical stages with respect to elevated SSC (Negri et al. 2019). Negri et al. (2019) propose a critical window of environmental sensitivity (CWES) for dredging activities: no dredging during the period of 3 days before the predicted night of spawning (to allow for suspended sediment to settle out of the water column), and 21 days afterwards to allow time for the larvae to settle.
We propose to use this CEWS (-3 to +21 days) for the dredging activities on Saba. Most coral species in the Northern Caribbean spawn during the months of July-September, some species (e.g. grooved brain coral, *Diploria labyrinthiformis*) have a wider season (with a distinct peak in June, Jordan, 2018; Bahamas Coral Innovation Hub, 2021). It is recommended to concentrate dredging activities in the 5-month period of December 1st to April 30th.

Alternative method

Recent monitoring of currents and turbidity has been done at the Black Rocks site. The measured average TSS was calculated at 25mg/l, with a variation between 0 – 80mg/l (see Annex 14). This is based on a generic correlation between FTU and TSS. It is recommended to continue this monitoring of the TSS (with OBS and ADCP) and validate the correlation by water (and sediment) sampling and measuring the actual suspended solids concentration in the laboratory. When this monitoring and validation is done, an alternative method can be used in defining threshold TSS level to be respected during construction. This method (referred to as the McArthur method, (McArthur et al, 2020) is based on the principle goal of preventing significantly greater exposure beyond that to which the coral community is presently adapted. With the validated TSS data, several threshold levels can be defined and linked to maximum duration and frequency. The TSS is monitored continuously during construction at the sensitive sites and compared against the set threshold and intensity levels to inform whether activities can continue or should be paused.

In absence of validated data, the threshold levels defined in this EIA will apply.

6.3 Road construction

For a large part, construction of the new road takes place along the trajectory of an existing, unpaved road (see also chapter 5). The new road will be 7-8 meters wide, while the current temporary road is 4-5 meters wide. For this widening, additional benching (for safety reasons) and (re)profiling of slopes of the hills is necessary (see chapter 5). The road crosses several steep and highly sensitive areas with respect to erosion. Large parts of the trajectory are already subject to heavy erosion.

During the construction period (2 years) and the subsequent years, and especially during periods of heavy rainfall, erosion in disturbed slopes will lead to significant intermittent release of sediments into the marine environment, high turbidity, high suspended solids concentrations (SSC), high temporal light reduction and high deposition of sediments to the seafloor.
When vegetation is allowed to re-establish (which can take several years, EPA, 1990), sedimentation slows down and becomes less significant. If vegetation does not recover, as is the case in different parts of the watershed area, erosion will be an ongoing process.

The road under construction will not be paved until the end of the construction activities (1,5 to 2 years after start of road construction). From literature it is known that unpaved roads are the single most important contributor to erosion and sedimentation in the Caribbean (Ramos-Scharron, 2006). Erosion and sedimentation form unpaved roads is 10.000 times higher than from vegetated areas.

The area's most prone to erosion are section 2 and section 4 of the access road, where slopes are particularly steep (see figures 5.1 and 5.11). In this area a rock-revetment to the south side of the road was installed to prevent further erosion by wave action. The marine area with highest expected impact is the area just south of this area, which is an area where relatively valuable "diffuse patch reefs" occur (see figure 6.3). A small seagrass bed in this area (see figure 6.3) will also be impacted by terrestrial sediments.

Unmitigated impact

Since terrigenous sediments are considered harmful to the marine environment, especially when they contain nutrients and organic matter (ISRS, 2004; Weber et al, 2006), unmitigated impacts for road construction are appraised as "severe", particularly for the short and mid-term, during construction and shortly thereafter.
Notwithstanding this, the planned reconstruction of the road can bring an opportunity to eventually decrease erosion in this already heavily impacted area (see "impact mitigation").

Impact mitigation

Impact mitigation will take place according to a number of principles: (1) keeping the period until paving of road as short as possible, (2) slope face stabilization, (3) revegetation of slopes, (4) adequate drainage of storm water near the road, (5) keeping area clean of fine materials.

Paving of unpaved roads as soon as possible. Paving of the access road -especially in combination with one of the mitigating measures summarized below, can almost fully restore the situation with respect to erosion to natural values (Ramos-Scharron, 2006, EPA, 1990). The period during which the road sections are left unfinished will be kept as short as possible. Nonetheless, this may take up to 1,5-2 years.

Slope stabilization can take place by means of rock anchors, wire mesh and netting (see figure 6.2, left). Rock anchors will be installed in a 2m x 2m grid (length of bolts: 50cm). These anchors will support a steel mesh and netting, preferably a biodegradable netting or blankets such as jute or coir. Installation of anchors will be done by drilling into the rock and filling the drilling hole with the anchor bolt and with grout for solid attachment. While reducing runoff velocity and keeping loose soil and rocks in place, the mesh and netting structure also optimize microclimate (mainly temperatures and moisture) for germination. In extremely steep areas (steeper than 1:1 H:V), confinement methods such as wire mesh confinement of cellular confinement may be considered. These methods also allow for the retainment of some soil.
In steep areas, slope stabilization by means of blankets of natural fibres (anchored), can reduce erosion by more than 75%. In combination with revegetation (e.g. hydroseeding, next paragraph), erosion can be reduced by 99% (Minnesota Storm Water Manual, 2018; EPA, 1990). Alternatives with equivalent effectivity may be selected.
Slope stabilization should start immediately after profiling of the slopes, well before road paving takes place.
South of the temporary road and south of section 2 of the road, a rock revetment is being installed for slope stabilization (see figure 5.11).

Revegetation can be supported by active seeding, e.g. by means of hydroseeding (spraying water with seeds) or terraseeding (spraying mulch with seeds). In order to avoid introduction of exotic species, and to use genetic material best adapted to the local environment, seeds of local origin and comparable habitats should be selected (Weisberg, 1993). Naturally occurring pioneers are grass species, such as *Aristida adscensionis* (mule grass), *Leptochloa panicea* (windgrass), *Digitaria horizontalis* (hay grass) and *Brachiaria purpurascens* (para grass). Use of *Bothriochloa pertusa* (donna grass) should be avoided, this species is a problematic invasive species for the Windward islands (Van der Burg et al, 2012).
Naturally occurring shrub species are: *Volkameria aculeate* (*haguebush*), *Acacia farnesiana* (*casha*), and *Randia aculeata* (black cherry).
When the slopes are steep as in the case of the flanks of St. Johns Hill, it is recommended to apply active seeding not as a single process, but in combination with slope stabilization. Figure 6.2 (bottom) shows an example of hydroseeding.

Successful revegetation can reduce erosion by 99% (Minnesota Storm Water Manual, 2018; EPA, 1990). Revegetation should start immediately after profiling and stabilization of the slopes, well before road paving takes place.
For this mitigating measure to succeed, **goat control** is essential (prevention of damage to young vegetation).

Drainage: Storm water will be diverted from the scarred part of the slope, by means of a drainage interceptor ditches along the contours of the hillside. For a graphical principle sketch of a drainage interceptor ditch, see figure 6.2, top right. In case of forecasted heavy rains during the construction works, the use of silt barriers (e.g. silt fences or straw bales) is advised.
Storm water which is collected on the (constructed) road will be drained towards the lower side of the road (sea side). At specified distances drainage holes in the wall along the road are constructed, where water can drain downhill.
At specific locations where the road is crossing a gut, (concrete) culverts will be constructed.

Cleaning of construction areas: All construction areas will be kept free of silt material being left exposed to erosion by wind or water. The surface must consist of compacted road base or original top soil.

Mitigating measures are particularly effective, but not all of the measures can be executed immediately. Paving of roads, for instance may take 1,5-2 years. Mitigated impacts can be regarded as “significant” for the short term (0-3 years). This may change to “positive” on the long term (>3 years) after road-paving, and especially when currently exposed hillsides will be stabilized and revegetated (see also table 6.7).

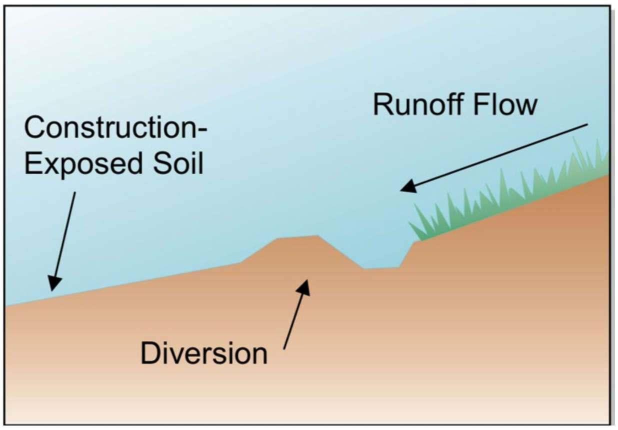


Figure 6.2: Left: example of anchored mesh system with netting of organic materials. Top right: example drainage interceptor ditch. Bottom: example of hydroseeding with wood mulch.

Table 6.7: Summary of impacts sedimentation from road construction

Erosion intensity (unmitigated)	High intensity: impacted surface (cleared of vegetation) is large; area of steep slopes
Sediment type	Coarse and fine sediments, possibly with organic content and nutrients (terrigenous origin)
Duration of impact	Several years, depending on timing of paving and revegetation, vegetation growth and goat control. This can be considered serious, see also figure 6.1
Frequency	Intermittent, during periods of (heavy) rainfall
Distance receptors from source	0-100 m: patch reefs; 100m seagrass bed
Sensitivity receptors	Sensitive
Protected species threatened	Patch reefs accommodate Montastraea species
Conclusion unmitigated impact (*)	Severe
Impact mitigation	Paving of unpaved roads, slope stabilization, revegetation, goat control, drainage, good housekeeping. Equivalent measures may be selected.
Effectivity impact mitigation	Slope stabilization is 75% effective; slope stabilization in combination with revegetation is 99% effective. Recovery of vegetation can take several years (EPA, 1990). Paving of roads will be executed towards the end of the construction period (after 1,5 years)
Conclusion mitigated impact (*)	Short term (0-3 years): significant Long term (>3 years): positive compared to current situation

(*) Severe, possibly severe, significant, moderate, low, insignificant, positive

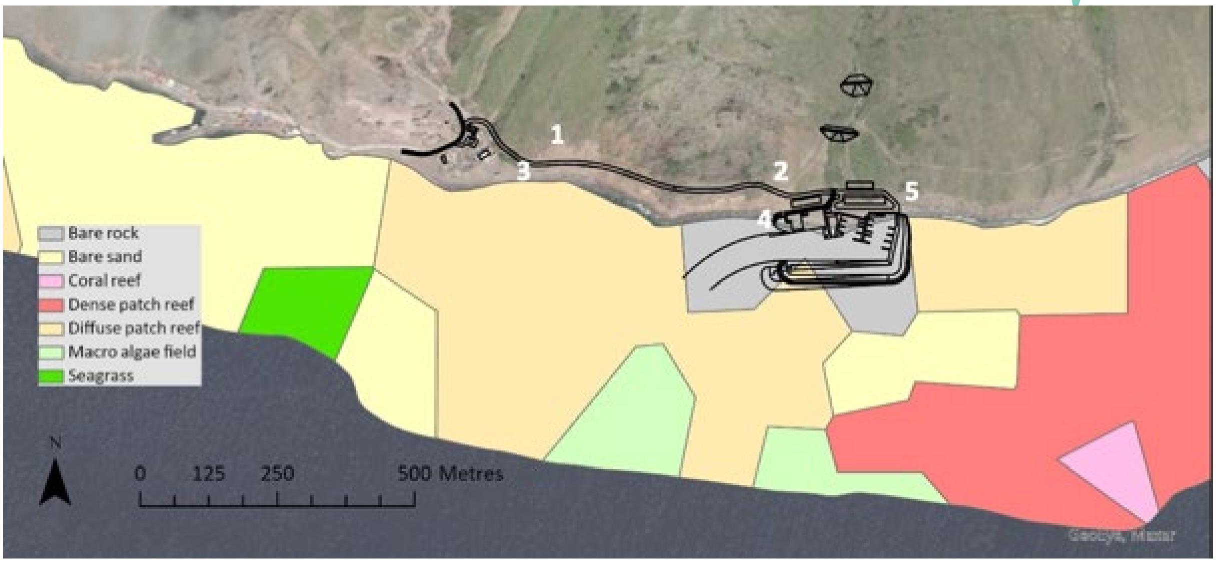


Figure 6.3: Marine nature values near critical construction sites with respect to erosion and sedimentation: 1: section 2 of access road; (2) section 4 of access road; (3) rock revetment; (4) outfall from gabion weirs; (5) landside of harbour area. Source base map: Kuramae et al, 2013
Water management in this figure is based on an earlier design with dams instead of gabion weirs.

6.4 Construction of gabion weirs

The series of small gabion weirs, necessary for proper water management in the area, will be constructed in an existing gutter. The proposed gabion weirs will slow down the water flow and allow water to infiltrate. This will contribute significantly to the reduction of runoff from the watershed area. However, the quality of the run-off is unknown and may be poorer (higher in sediments) than run-off in the current situation.

Run-off from the weirs will enter the sea just west of the breakwater (see figure 6.4), in an area protected from the main currents and waves by the breakwater. In this area circulation of seawater will be considerably less than in the current situation without a breakwater (see also chapter 7). The impacted area can be characterized as an area covered with bare rock and relatively low coral cover (1,6%, see chapter 4), but the area is rich in protected elkhorn coral (Acropora palmata, see figure 5.17). Since these colonies are in the high-risk zone, they will be removed from the area before construction of the harbor.

Unmitigated impact

The severity of unmitigated impacts by runoff, related to the construction of weirs is appraised as “moderate” (see also table 6.8).

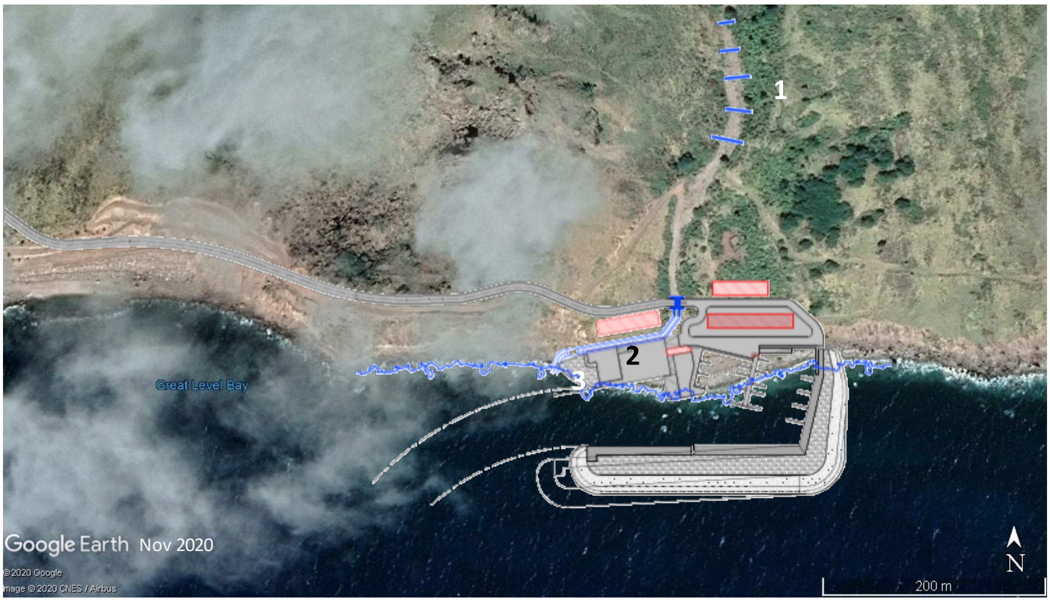


Figure 6.4: Discharge of runoff from weirs: 1. weirs; 2. discharge channel (run-off); 3. Outlet

Impact mitigation

In the drainage system to sea **a sand catchment box** will be installed, which reduces emissions of relatively coarse sediments. A sand catchment box is not effective with respect to fine sediments because water velocities in the device remain high.

Mitigated impact is appraised as “moderate-low”, in the long term possibly positive compared to current situation (see also table 6.8).

Table 6.8: Summary of impacts: sedimentation from construction of weirs

Load intensity (unmitigated)	Moderate. Large part of run-off collected, however quality of runoff unknown.
Sediment type	Coarse and fine sediments, possibly with organic content and nutrients (terrigenous origin[1])
Duration of impact	Months to years depending on vegetation regrowth (and goat control) and stability of basin floor
Frequency	Frequency of high runoff events strongly reduced by weirs, only during severe storms (approximately one event 2-5 years)
Distance receptors from source	50 meters: stands of *Acropora palmata,* however these are in high-risk zone and will be relocated; 200 m: patch reefs
Sensitivity receptors	Sensitive
Protected species threatened	Stands of *Acropora palmata* (high-risk zone: to be relocated)
Conclusion unmitigated impact (*)	Moderate, in the long term possibly positive compared to current situation
Impact mitigation	Revegetation, goat control. Installation of a sand catchment box.
Effectivity impact mitigation	Recovery of vegetation can take several years (EPA, 1990). The sand catchment box has limited effect.
Conclusion mitigated impact (*)	Moderate-low, in the long term possibly positive compared to current situation

(*) Severe, possibly severe, significant, moderate, low, or insignificant

[1] Terrigenous sediments are considered harmful to the marine environment, especially when they contain nutrients and organic matter (ISRS, 2004; Weber et al, 2006)

6.5 Levelling and profiling of harbor area

In the landside harbour area, large scale ground works will take place (total area 1,2 ha). Although the area is rather flat, it is a large area and it is at close distance to sea. Runoff from lower parts of the watershed will not be collected by the weirs and will be poorer in quality than in the current situation, because of the lack of vegetation. The excavated lands may be fallow for a long time (several years) before construction of buildings actually starts.

Unmitigated impact

The unmitigated impact is considered “severe”.

Impact mitigation

Weirs, including gutters to the discharge location, must be constructed before levelling of harbor area takes place, otherwise extreme erosion and sedimentation will take place.
Phased execution or temporal revegetation is needed to prevent erosion in the period that the area is not fully in use’. Preferred is a phased execution, by only levelling areas just before construction of the building. Otherwise revegetation is an option for large areas are still unpaved. This needs to be initiated as soon as possible after levelling of the area.
Slope stabilization (between vertical levels) needs to be initiated as soon as possible.
Construction of a bund system is needed to control runoff. Bunds are often used as a measure of soil conservation, by means of creating an obstruction across the path of surface runoff to reduce the velocity of flowing water. It retains the runoff water and thus helps to control soil erosion. **Gabions** (rocks held together by steel wire) may also be used for this.

Mitigated impacts are considered “significant” for the short term because of the time needed to have full effect from the mitigating measures (especially temporal revegetation).
For the long term impacts are qualified “moderate”, but this also depends on the ratio paved/ unpaved and vegetated/unvegetated in the area.

Table 6.9: Summary of impacts: sedimentation from levelling of landside area of harbor

Load intensity (unmitigated)	Severe. Vegetation removed in large area
Sediment type	Coarse and fine sediments, possibly with organic content and nutrients (terrigenous origin[1])
Duration of impact	Months to years depending on vegetation regrowth (and goat control)
Frequency	Intermittent, during periods of (heavy) rainfall
Distance receptors from source	50 meters: stands of *Acropora palmata,* however these are in high-risk zone and will be relocated; 200 m: patch reefs
Sensitivity receptors	Sensitive
Protected species threatened	Stands of *Acropora palmata* (high-risk zone: to be relocated)
Conclusion unmitigated impact (*)	Severe
Impact mitigation	Slope stabilization, temporal revegetation, paving of areas
Effectivity impact mitigation	High (75-90% reduction)
Conclusion mitigated impact (*)	Significant (short term), moderate (long term)

(*) Severe, possibly severe, significant, moderate, low, or insignificant

[1] Terrigenous sediments are considered harmful to the marine environment, especially when they contain nutrients and organic matter (ISRS, 2004; Weber et al, 2006)

6.6 Construction of the breakwater (quantitative assessment)

General

The construction of the breakwater will result in suspension of fine sediments, leading to a sediment plume, which spreads out in westerly directions (predominantly) or in easterly directions (in case of current reversal). The level at which this process takes place depends on the method used. For our calculations we used the method of construction of the berm breakwater (see chapter 3). This construction method can be regarded as a "worst case", since placement of the aggregates is in the open sea, subject to waves and currents. For the construction method we used the highest source term factor[1]: 0.05 (Laboyrie et al., 2018; also see table 6.10).
For modelling purposes, we use a volume of core material (quarry run) of 17.500m3[2], a net construction period of 3 months, while the gross construction period (including downtime) is 15 months.

The assessment of the environmental and ecological response to a sediment plume is carried out by means of a hydrodynamic transport model, D-Flow FM and Water Quality. The models simulate the processes driving sediment dispersion: advection, diffusion and settling and re-suspension. Predicted water quality near sensitive receptors has been translated to environmental and ecological risk, by comparing concentrations and deposition of sediment to critical values from literature (see paragraph 6.2). Annex 11 contains relevant information with respect to the use of the model and relevant modelling assumptions.

It is emphasized that the results of the modelling calculations must be regarded with caution, since the results cannot be related to hydraulic background data (such as current velocities) and water quality data (suspended solids concentrations/SSC, deposition, see also chapter 4). Furthermore, spatial and temporal variations in source intensity are difficult to predict. Although these variations are expected to be limited, (see further in this paragraph), they may influence the occurrence of peak concentrations in the water column.

The impacts by construction of the landside quays and RoRo quay (backfilling) are not assessed in a quantitative manner. These are considered insignificant, since construction takes place in a dry space, with the use of combiwalls. Likewise, the construction of the revetment of the RoRo quay has not been modelled in a quantitative way, because the volume is small (700-1000m3), and the revetment is largely constructed above the waterline.

Critical construction phases

During the construction of the berm breakwater 17.500 m3 of quarry run aggregates (10/500kg – 10/1000kg) will be released to the open seafloor, before it is covered with larger rocks (see chapter 3)[3]. Additionally, 10.000 m3 of material will be used for backfilling of the main quay. This material may originate from the nearby quarry or from the local beach. By nature, this material includes fine particles (< 63 µm), either resulting from the crushing process or from natural accumulation. A certain fraction of these fine particles will go into suspension during marine construction. For the modelling we used the characteristics of the aggregate material present in the beach area. This material consists for 33% of fine particles (< 63 µm, see for particle size distribution annex 4)[4].

[1] Percentage of fines entering in the sediment plume

[2] Total volume: 26.500m3 minus 9.000 m3 (applied above water)

[3] The total volume of 17.500 m3 core material for the construction and 10.000 m3 for backfill (quays) is applied over 5 phases (2.1-2.5)

[4] This is an overestimation of fines present in the bottom of the seafloor, since a significant fraction of the cores consists of rock material which was not sampled for analysis. Also, the specifications for applying of quarry run and armor defines a maximum of 5% fines (63 µm)

Two situations have been modelled, corresponding with 2 critical phases in the construction process. These phases are critical because the activities take place near sensitive patch reefs:

- Phase 2.1. Beginning of construction of breakwater (core material, quarry run); no breakwater structure (yet) in place. Placement of aggregates in open, shallow water by means of excavators. Several patch reefs nearby, especially patch reef nr. 4 (see figures 6.5 and 6.6). The duration of phase 2.1 is 2,5 weeks (net construction time, hydraulically modelled) to 10 weeks (gross construction time, not modelled).
- Phase 2.5. Final parts of construction. Placement of core material (quarry run) for breakwater and backfilling for main quay. Breakwater structure largely in place with hydraulic impact on currents and dispersion. Several patch reefs nearby (especially patch reef 2, see figures 6.5 and 6.6). The duration of phase 2.5 is 2,5 weeks (net construction time, modelled) to 10 weeks (gross construction time, not modelled).

During the placement of armour rock (with large rocks) no significant amounts of fine sediments will suspend in the water column (< 0,1% fines).

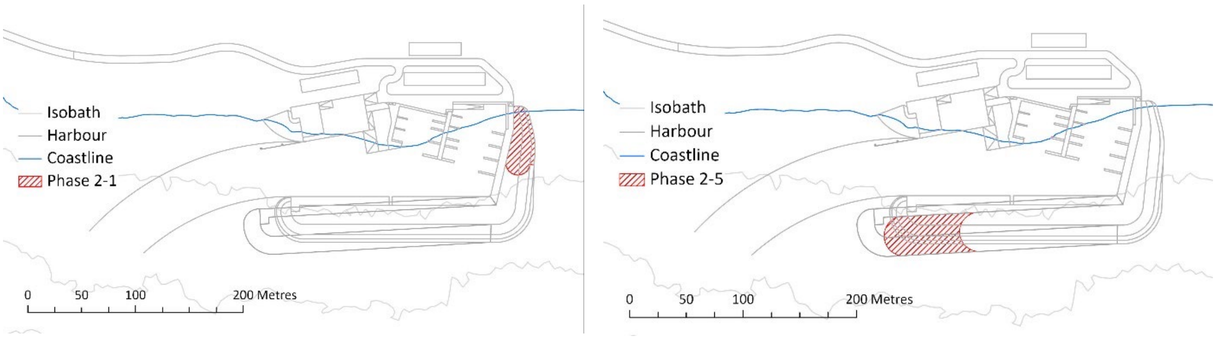


Figure 6.5 Two critical phases of construction used for quantitative impact assessment (phase 2.1 to the left and 2.5 to the right, indicated by hatched part of the breakwater)

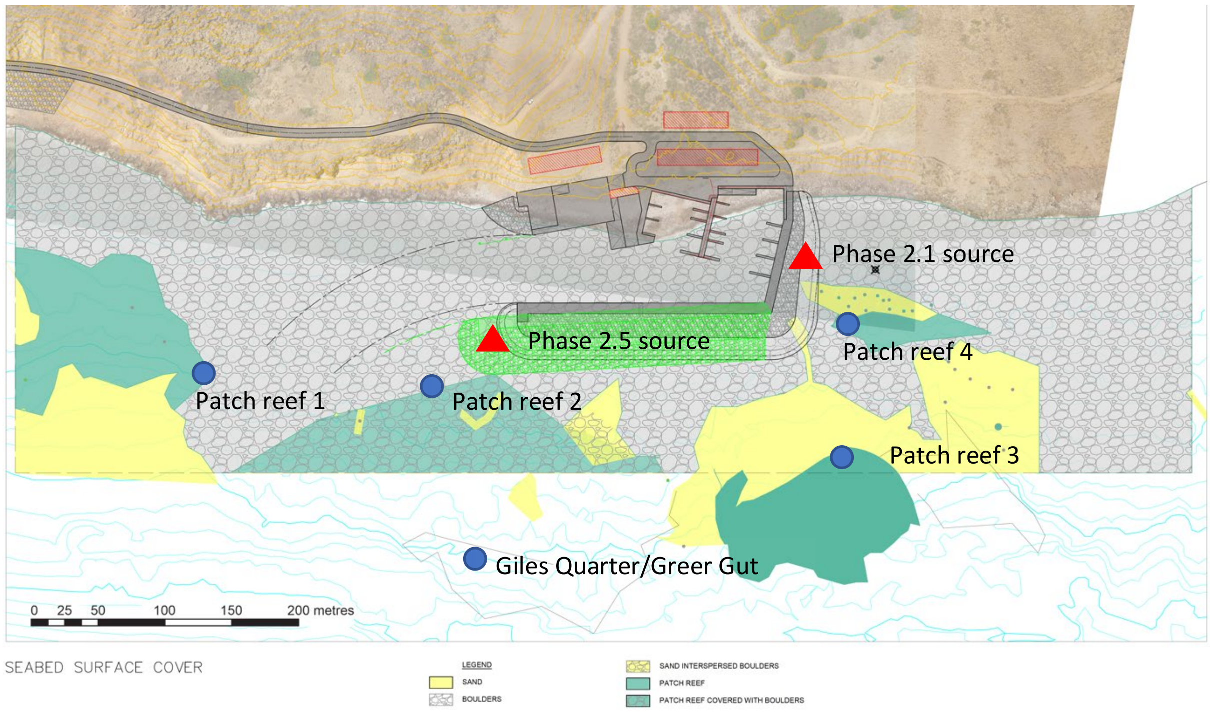


Figure 6.6: Modelled locations of placement of aggregates and calculation points for the 4 patch reefs and the Giles Quarter/Greer Gut dive site.

Table 6.10 presents relevant input data for the hydraulic modelling.

Table 6.10 Relevant model input for construction phases 2.1 and 2.5

	Unit	Amount
Volume of core material for breakwater per phase	m3	3,500
Volume of backfill material (phase 2.5)	m3	2,000
Dry density	kg/l	1.5
Particle density	kg/l	2.75
Porosity		0.45
Fraction of fines <63µm (annex 4)		0.33
Fraction <20µm (annex 4)		0.09
Fraction < 6µm (annex 4)		0.02
Fraction < 2µm (annex 4)		0.001
Operational hours per week (12 hrs per day)	hr	84
Production rate (avg)	m3/hr	16
Source term factor for placement in sea[1]		0.05
Source term fines <63 µm (*)	kg/sec	0.11
Duration of phase 2.1 and 2.5 (each)	weeks	2.6

(*) For calculation, see annex 11

The source term of 0.11 kg/s is entered in the hydraulic model (D-Flow FM/Water Quality) as a constant value. In reality the source term may vary, both in a spatial and a temporal sense. Spatial variability is limited since construction progresses slowly from day to day. Temporal variability may occur when differences in construction material (aggregates) are to be expected and when tipping of core material is intermittent. In the model used, we assume that this is not the case, i.e. uniform aggregates which are continuously distributed by a hydraulic excavator.

Impacts on patch reefs (unmitigated)

For phase 2.1 and 2.5 of the construction of the breakwater, suspended solids concentration (SSC) and sediment deposition were calculated for a number of critical locations, over a 1-month design period: a representative month with several brief reverse current periods. For SSC (table 6.11), the average of all daily values (06.00-18.00 hours) is selected, excluding the night values, in which no activity takes place.
For deposition, both mean and maximum daily values are presented in table 6.12[2]. In annex 11, a brief explanation is given about the calculation of the mean daily deposition rates and the maximum daily deposition rates.

Concentrations of suspended solids (SSCs) at the 4 patch reefs are relatively low during construction, except for patch reef 2. The maximum value of excess SSC (15 min average) at this reef during construction phase 2.5 is 4,4 mg/l (see annex 13). The threshold value of 2 mg/l is exceeded for 14% of the time at this reef (annex 13, table 6.6 and table 6.8: “moderate impact”).

From table 6.9 it can be observed that average daily deposition of fine sediments (all fractions < 63 µm) is relatively high at reef nr. 4 during construction phase 2.1 (first phase of construction) and at reef nr. 2 during construction phase 2.5 (last phase of construction), which can be classified as “minor” and “moderate” impact respectively.

Relatively low values for deposition are found at reef 1 during phase 2.5. The main reason for this is that 73% of the particles smaller than 63 µm consists of the class of 63-20 µm (representative

[1] Fraction of total fines brought into suspension by method used. Factor is the highest factor, corresponding with placement in open sea, with mechanically dredged material (as opposed to hydraulically dredged). Source: Dredging for sustainable infrastructure (2018)

[2] The average daily deposition is calculated by calculating the cumulative deposition over the design months and dividing the value by the number of days in that month. Maximum daily deposition is found by taking the maximum increment over 24 hours during the design month

diameter 47 µm[1]). The referenced vertical velocity of these particles is 8.1 m/h. Therefore, at a current velocity of 10 cm/s the majority of these particles are deposited to the seafloor before they reach reef 1.
Another reason for the low values at reef 1 (during phase 2.5 of construction) may be that the breakwater - in this stage almost completed - creates a vortex-like counter current just west of the breakwater, causing the plume to bend in a northward direction (see figure 6.8).

Calculated peak sediment depositions (maximum 7.7 mg cm^{-2} day^{-1}, see table 6.9) are relatively low compared to naturally occurring events such as hurricanes. As an example, hurricane Isaac (August 2012) can be mentioned, which resulted in values of 12-17 mg cm^{-2} day^{-1} as month averages near Saint James Island and Little St. James Island (NOAA, 2015).

It must be noted, that the accuracy of the hydraulic model used decreases when used for sensitive objects very near to the source, i.e. less than approximately 150-200 meters, because in this area still nearfield (turbulent) processes and density currents take place (Tuinhof, 2014). These values should therefore be regarded with caution. This is especially true for the situation with respect to reef 4 during construction phase 2.1 and reef 2 during construction phase 2.5 (see also figure 6.6).

The official dive sites of Giles Quarter and Greer Gut, located approximately 150m to the south of the breakwater (figure 6.6), are not considered to be in the critical zone with respect to SSC elevation and deposition of fine sediments during construction.
Separate analysis (not summarized in tables 6.8 and 6.9) points out that the dense patch reefs, occurring east and southeast of reef 4 (see figure 6.3 in paragraph 6.3), are not impacted in any significant way by construction, because of their presence at greater distance from the source (more than 200 meters south and eastward and up current).

The construction of the alternatives “cofferdam structure” or “caisson structure” result in lower levels of resuspension and sedimentation than the base alternative “berm breakwater”, because the filling of these structures and the ballasting take place in a controlled manner in semi confined spaces instead of placement of the quarry run on the open seafloor, resulting in less (peak) emissions. In addition, considerably less armour rock is needed for scour protection.
For the caisson structure, levelling of the seafloor needs to take place and a layer of gravel of 30-50 cm needs to be added on top of the seafloor. This will lead to a brief period with (re)suspension and dispersion of fine sediments in the water column. Since local marine sediments contain limited amounts of silt and clay (maximum 2-3%, see chapter 4), this effect is expected to be limited. Furthermore, bed preparation is superficial (no excavations) and concerns mostly relocation of rocks and boulders. The release of fine sediments during bed preparation is therefore considered to be insignificant.
For a cofferdam structure, no seabed preparation is necessary.

With regard to the impacts of marine construction, we consider the unmitigated impact on the reefs closer to the source than 200 meters (mainly reef nr. 2 and 4) “significant”, partly because of uncertainties with respect to the short distance between source and sensitive object (less than 200m). It must be noted here that patch reef nr. 2 is largely in the high risk zone and that protected corals are planned to be relocated from this area.
Unmitigated impacts on reefs further than 200 meters (reefs nr. 1 and 3 and Giles Quarter/Greer Gut) are considered “moderate”.

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[1] Formula for determining representative particle size for a certain class (R = radius): $R_{rep} = \sqrt{\frac{1}{2}\frac{R_{max}^4 - R_{min}^4}{R_{max}^2 - R_{min}^2}}$

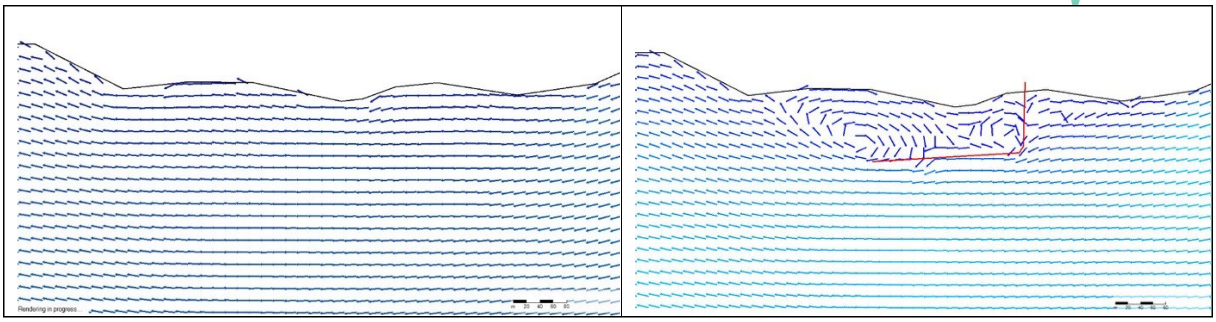

Figure 6.7 Current pattern (predominant) without the breakwater structure (phase 2.1) and with the breakwater structure in place (phase 2.5)

Impact mitigation and mitigated impact

Reducing releases of fine sediments to the water column will be realized by **not using any material with high contents of fines** (e.g. from area near BH3) for marine construction and by **screening out fine fractions (<10mm)** from the aggregates before using the aggregates in the marine works. Screened aggregates will be tested and approved for total contents of fines (<63µm) which should be less than 5%. This measure will reduce SSC's and sediment depositions by more than a factor 5 (5% instead of 33%).

Because the patch reef eastward of the breakwater (reef 4) is very close to the source in phase 2.1, and therefore very vulnerable especially in situations of reverse current conditions, it is strongly recommended to **discontinue construction**, especially core construction with mixed aggregates, within 3 hours **after a current reversal**.

If the choice is made for a **caisson structure or a cofferdam**, SSCs and sediment deposition at the patch reefs will be considerably lower, because of the smaller footprint of these types of structures and the resulting increased space between source and sensitive object (especially reef nr. 2 and 4). If the choice is made for a berm breakwater including a smaller **caisson structure at the quay side** of the breakwater (see figure 3.7 lower part in chapter 3), this will result in the use of 35% less backfill material and considerably lower turbidity and sedimentation.

If the choice is made for a caisson structure for the whole breakwater, the aggregates used as a base layer for the structure will be screened to exclude the fraction of <10mm. Furthermore it is recommended to, during ballasting, pump away sediment loaded water to deeper waters (100+ meters deep), thereby minimizing sediment impacts for the nearby patch reefs.

Coral spawning, environmental window: Negri et al 2019 propose to use a critical window of environmental sensitivity (CWES) for dredging activities (see next paragraph). It is considered good practice to also apply this for construction activities. The CWES for dredging means that no activities take place between 3 days before spawning and 21 days after spawning (-3 to +21 days). Most coral species in the Northern Caribbean spawn during the months of July-September, some species have a wider season (see paragraph 6.2).

The use of **silt screens is considered ineffective** during construction of the breakwater, because of possible high waves (>1 meter) and relatively strong currents.

A combination of **monitoring of water quality and coral health and ongoing dispersion modelling** is a good approach to guide decisions on construction (e.g. when to modify or even temporally stop construction (see also Laboyrie et al, 2018).

Minimizing content of fines to < 5% and discontinuing construction during current reversal are considered particularly effective mitigating measures.

Tables 6.13 and 6.14 present the values for SSC and sediment deposition in case of using aggregates with a maximum of 5% fines. No impact is expected with respect to average SSC, peak SSC and deposition, except for patch reef 2 during construction in phase 2.5 (slight impact from deposition).

Since the modelling of suspended solids concentrations and sediment deposition on the reefs nearer to the source than 150-200m can only be done with limited accuracy (see also previous section), the results with respect to patch reefs 2 and 4 must be treated with caution. Again it is noted here that patch reef 2 is largely in the high risk zone and that protected corals are planned to be relocated from this area. For patch reef 4 this is not recommended since it is upstream of the sources, and construction can be stopped in case of current reversals.

Based on the results described in this section, mitigated impact from SSC and sedimentation by construction of the breakwater is considered "moderate" for patch reef 2 and "low" for the other patch reefs, particularly outside the high-risk zone.

Table 6.11 Excess SSC expressed as average and percentage of time > 1 mg/l and > 2 mg/l at 4 nearby patch reefs and dive site (Giles Quarter/Greer Gut, **unmitigated**)

Activity	Unit	Patch reef 1	Patch reef 2	Patch reef 3	Patch reef 4	Giles Q./GG
Construction phase 2.1	SSC average mg/l	0,0	0,1	0,1	0,3	0,0
	% of time >1 mg/l	0,0	0,0	0,0	**5,6**	0,0
	% of time >2 mg/l	0,0	0,0	0,0	0,0	0,0
Construction phase 2.5	SSC average mg/l	0,1	**1,2**	0,0	0,0	0,0
	% of time >1 mg/l	0,0	**17,9**	0,0	0,0	0,0
	% of time >2 mg/l	0,0	**13,8**	0,0	0,0	0,0

Color indication: no color = no impact; green=slight impact; yellow=minor impact; orange=moderate impact; red= major impact

Table 6.12 Excess sediment deposition (all fractions: 63µm-20µm, 20µm-6µm, < 6µm) during construction at 4 nearby patch reefs and dive site (Giles Quarter/Greer Gut, **unmitigated)**

Activity	Unit	Patch reef 1	Patch reef 2	Patch reef 3	Patch reef 4	Giles Q./GG
Construction phase 2.1						
Average daily deposition	mg cm^{-2} day^{-1}	0,1	0,3	0,2	**1,5**	0,0
Maximum daily deposition	mg cm^{-2} day^{-1}	0,1	0,6	0,9	4,4	0,2
Construction phase 2.5						
Average daily deposition	mg cm^{-2} day^{-1}	0,3	**3,3**	0,2	0,1	0,1
Maximum daily deposition	mg cm^{-2} day^{-1}	0,7	7,7	1,6	2,0	0,8

Color indication: no color = no impact; green=slight impact; yellow=minor impact; orange=moderate impact; red= major impact

Table 6.13 Excess SSC expressed as average and percentage of time > 1 mg/l and > 2 mg/l at 4 nearby patch reefs and dive site (Giles Quarter/Greer Gut, **mitigated: maximum 5% fines instead of 33%**)

Activity	Unit	Patch reef 1	Patch reef 2	Patch reef 3	Patch reef 4	Giles Q./GG
Construction phase 2.1	SSC average mg/l	0,0	0,0	0,0	0,1	0,0
	% of time >1 mg/l	0,0	0,0	0,0	0,0	0,0
	% of time >2 mg/l	0,0	0,0	0,0	0,0	0,0
Construction phase 2.5	SSC average mg/l	0,0	0,2	0,0	0,0	0,0
	% of time >1 mg/l	0,0	0,0	0,0	0,0	0,0
	% of time >2 mg/l	0,0	0,0	0,0	0,0	0,0

Color indication: no color = no impact; green=slight impact; yellow=minor impact; orange=moderate impact; red= major impact

Table 6.14 Excess sediment deposition (all fractions: 63µm-20µm, 20µm-6µm, < 6µm) during construction at 4 nearby patch reefs and dive site (Giles Quarter/Greer Gut, **mitigated: maximum 5% fines instead of 33%**)

Activity	Unit	Patch reef 1	Patch reef 2	Patch reef 3	Patch reef 4	Giles Q./GG
Construction phase 2.1						
Average daily deposition	mg cm^{-2} day^{-1}	0,0	0,1	0,0	0,2	0,0
Maximum daily deposition	mg cm^{-2} day^{-1}	0,0	0,1	0,2	0,7	0,0
Construction phase 2.5						
Average daily deposition	mg cm^{-2} day^{-1}	0,1	**0,6**	0,0	0,0	0,0
Maximum daily deposition	mg cm^{-2} day^{-1}	0,1	1,3	0,3	0,3	0,1

Color indication: no color = no impact; green=slight impact; yellow=minor impact; orange=moderate impact; red= major impact

6.7 Dredging of the harbor basin (quantitative assessment)

General

One of the anticipated impacts of dredging is the generation of suspended sediment plumes. These plumes may cause environmental and ecological loss such as light reduction, release of contaminants (not applicable, see chapter 4) and sedimentation at sensitive receptors such as corals and sponges (see also paragraph 6.1).

The impacts from dredging are assessed by using the hydrodynamic and suspended sediment transport model Delft3D. As was the case for marine construction, we emphasize that the results of the modelling calculations must be regarded with caution, since the results cannot be related to hydraulic background data (current velocities) and water quality data (suspended solids concentrations/SSC, deposition), and spatial and temporal variations in source intensity are difficult to predict.

Critical phases during dredging

Dredging of the total volume of 30.000 m3 of sediment takes place during a period of approximately 3 months (see also chapter 3).

Two phases of the dredging operation have been modelled. The first phase (east basin) was modelled with and without a silt screen:

- Phase 1: Dredging of east basin (see figure 6.8). Dredged volume: 20.000 m3. The breakwater structure is fully in place. Sample BH3 is representative for the sediment characteristics (annex 3 and 4). Dredged material contains a maximum of 33% of fines (<63µm, see annex 4). Dredging is modelled with and without silt screen. Duration of dredging in phase 1 is 8 weeks. Since dredging starts when the breakwater structure is fully in place, patch reefs 1 and 2 are most near to the source of sediments (see figures 6.9 and 6.10).
- Phase 2: Dredging of western parts of harbor basin and approach channel (see figure 6.9). Dredged volume: 10.000 m3. Sediments of B3, B7 and B9 (figure 4.3 of this report and annex 4) are representative for the dredged material (and assumed to contribute to suspended fines equally). Dredged material contains 13% of fines (<63µm). Dredging takes place without a silt screen; conditions for using a silt screen are not adequate, because of waves and currents in the area. The duration of phase 2 is 4 weeks. Patch reefs 1 and 2 are the reefs most near to the source of sediments (see figures 6.8 and 6.9).

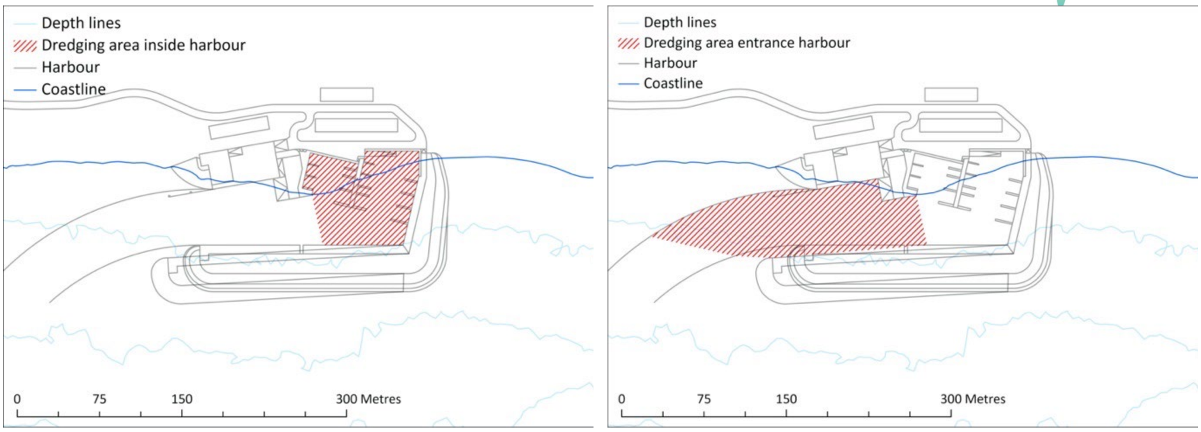

Figure 6.8 Dredging area east part of harbor (phase 1, left) and west part of harbor including approach channel (phase 2, right)

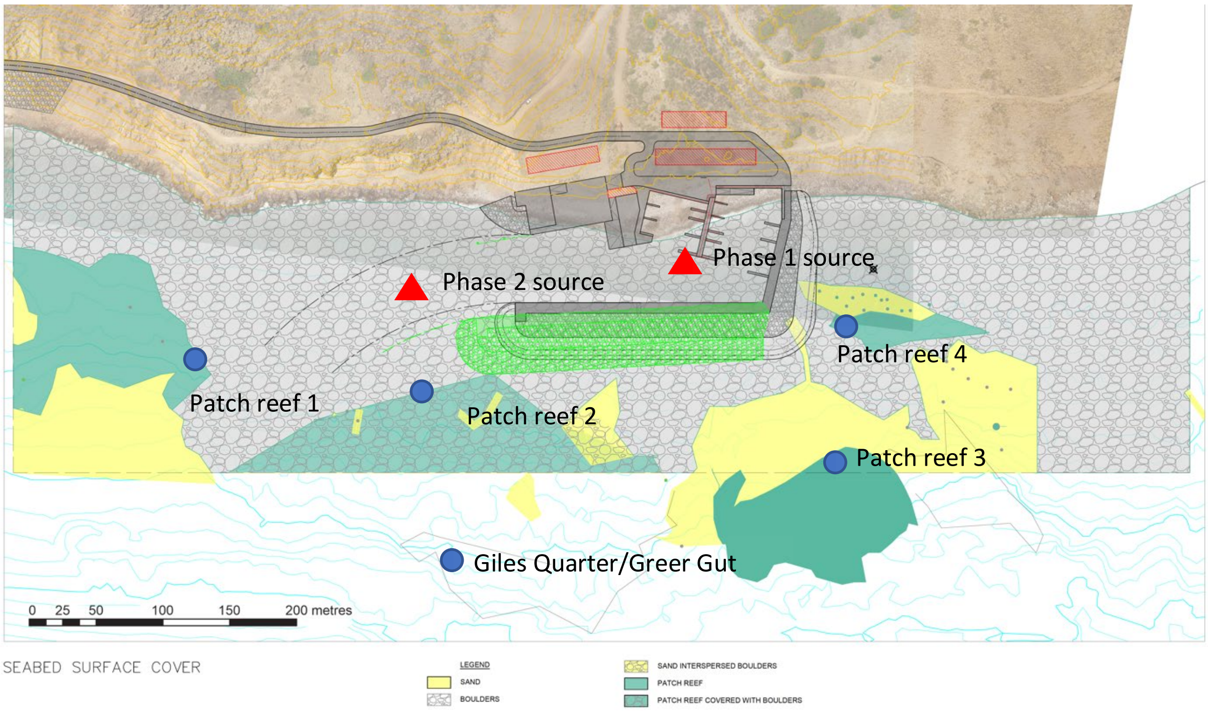

Figure 6.9: Modelled source locations of dredging and calculation points for the 4 patch reefs and Giles Quarter/Greer Gut

Table 6.15 presents relevant input data for the hydraulic modelling. Annex 11 includes the exact coordinates of the modelled source locations and the coordinates of the calculation points for deposition and TSS (at the sensitive objects).

Table 6.15 Relevant model input for dredging of east and west part of harbor

	Unit	East part without silt screen	West part without silt screen
Volume of dredged material	m3	20,000	10,000
Dry density	kg/l	1.33	1.33
Particle density	kg/l	2.75	2.75
Porosity		0.45	0.45
Fraction of fines <63µm (annex 4)		0.33	0.13
Fraction <20µm (annex 4)		0.09	0.04
Fraction < 6µm (annex 4)		0.02	0.008

Fraction < 2µm (annex 4)		0.001	0.0004
Operational hours per week (12 hrs per day)	hr	84	84
Production rate (avg)	m3/hr	40	40
Source term factor for dredging[1]		0.10	0.10
Source term fines <63µm phase(*)	kg/sec	0.55	0.22
Duration of phase 2.1 and 2.5 (each)	weeks	8	4

(*) For retention of fines
(**) For calculation, see annex 11

The source term of 0.55 and 0.22 kg/s are entered in the hydraulic models (D-Flow FM and Water Quality) as constant values. In reality these source terms may vary, both in a spatial and a temporal sense. Spatial variability is limited since dredging progresses slowly from day to day. The daily spatial variation is not more than 15 meters in all directions (1 cell within modelling mesh). Temporal variability may occur when differences in fines concentration exist in the seafloor. In the model calculations we assume that this is not the case within the course of one day of working.

Impacts on patch reefs (unmitigated)

For the 2 phases of the dredging operation, suspended solids concentration (SSC) and sediment deposition were calculated for critical locations, over a 1-month design period (a representative month with several brief reverse current periods, see table 6.16). For SSC, only values between 08.00 and 18.00 were regarded, excluding the night values, in which no activity takes place. For deposition, both mean daily values and maximum daily values are presented in table 6.17[2]. In annex 11, a brief explanation is given about the calculation of the mean daily deposition rates and the maximum daily deposition rates.

Figure 6.11 shows patterns of suspended solids concentration and (cumulative) deposition at patch reef 1 during 1 month of dredging (dredging phase 2).

Concentrations of suspended solids (SSCs) at the 4 patch reefs are relatively low during dredging, except for patch reef 2. The maximum value of excess SSC (15-min average) at this reef during phase 2 of dredging is 2,3 mg/l (see annex 13). The threshold value of 1 mg/l is exceeded for 11,4% of the time at this reef (annex 13, table 6.6 and table 6.11: “minor impact”).

From table 6.13 it can be observed that average daily deposition of fine sediments (all fractions < 63 µm) is relatively high at reef nr. 2 during phase 2 of dredging, which can be classified as “moderate”.

Possible reasons for the low SSCs at relatively short distances from the source are the low dredging capacity deployed and the relatively low ratio of fines smaller than 20 µm (27% of total particles smaller than 63 µm).
SSC and sediment deposition are calculated on the basis of average dredging capacity, which is rather low (10-100 times lower than most projects studied, see also par. 6.2). If, for any reason, work pace should be accelerated temporarily, then higher average and peak values will be observed.

It must be noted, that the accuracy of the hydraulic model is limited when used for sensitive objects at close distance from the source -less than approximately 150-200 meters- because in this area still nearfield (turbulent) processes and density currents take place (Tuinhof, 2014). These values should therefore be regarded with caution and monitoring of real values during the operation remains very

[1] Fraction of total fines brought into suspension by method used. Factor selected is the highest factor, corresponding with dredging by means of backhoe dredger (BHD). Source: Laboyrie et al, 2018

[2] The average daily deposition is calculated by calculating the cumulative deposition over the design months and dividing the value by 31. Maximum daily deposition is found by taking the maximum increment over 24 hours during the design month

important (see mitigating measures). This is especially true for the situation with respect to reef 1 and 2 during dredging of the approach channel (see also figure 6.9).

The official dive sites of Giles Quarter and Greer Gut, located approximately 150m to the south of the breakwater (figure 6.9), are not considered to be in the critical zone with respect to deposition of fine sediments and SSCs during dredging.
Separate analysis (not presented in tables 6.16 and 6.17) points out that the dense patch reefs, present east and southeast of reef 4 (see figure 6.3 in paragraph 6.3), are not impacted in any significant way by dredging, because of their presence at greater distance from the source (more than 200 meters south and eastward).
Sediments in the area of the proposed harbor are poor in organic matter. The average value is less than 0,7%. Typical values for dredging projects near the harbors in Aruba and Curaçao are 3-21% (pers. comm. Geotron). Low concentrations of organic matter are favorable for coral survival (see paragraph 6.1). The marine sediments in the footprint area can be considered to be free of chemical pollution (see also chapter 4).

Calculated peak sediment depositions (maximum 5.8 mg cm^{-2} day^{-1}, see table 6.17) are relatively low compared to naturally occurring events such as hurricanes (e.g. hurricane Isaac. In St. Thomas: 12-17 mg cm^{-2} day^{-1}, as a month average, NOAA, 2015).

With regard to the impacts of dredging, we consider the unmitigated impact on patch reef nr. 2 as "significant", partly because of uncertainties with respect to the modelling results at short distances between source and sensitive object (less than 200m).
Impacts on reefs further than 200 meters (reefs nr. 1, 3, 4 and Giles Quarter/Greer Gut) are regarded as "moderate".

Impact mitigation and mitigated impact

The choice to start **dredging** only **after completion of the breakwater** is a mitigating measure on itself. This situation makes dredging in quiet waters with less waves and currents possible, which promotes the accuracy of the work, and reduces the efforts of holding station and reduces propeller wash. Another important factor related to the existence of the breakwater at the time of dredging however, is the possibility of using silt screens (see further).
In the PIANC report (2010) an overview of mitigation options for dredging projects is presented. The most relevant options for this project are the following:

Choice of equipment and minimization of sediment spill: Compared to a trail suction hopper dredger (TSHD), the proposed backhoe dredger (BHD) has a number of advantages: (1) smaller vessels allow that dredging can take place in all corners of the dredging area and (2) BHD typically causes lower emission of fine sediments (Laboyrie, 2018)[1].
Where **closed buckets** can be used for the BHD, the sediment spill caused by the BHD can significantly be reduced. According to Laboyrie (2018) source term factors of 5% are feasible, meaning that the amount of sediments available in the plume will be 50% less than in the unmitigated scenario.

Dredging accuracy: Over-dredging, is a practice sometimes applied by contractors to assure compliance with the contract, however this practice leads to higher volumes of dredged material and hence to higher sediment spills. In dialogue with the contractor (and if necessary by stipulation in a permit) this must be prevented as much as possible.

[1] Maximum value for the source term fraction for a BHD is 10% (dispersion of total fine sediments) while the maximum value for a TSHD is typically between 15 and 20%.

Temporarily relocate dredge activity: In cases in which environmental or ecological criteria are exceeded in certain areas, it can be decided to change the dredging activity, or relocate the activity to another area until the situation in the area under consideration is stabilized. This approach is often a part of socalled "adaptive management" and involves monitoring of sensitive areas.

Coral spawning, environmental window: As discussed in the previous paragraph, Negri et al 2019 propose to use a critical window of environmental sensitivity (CWES) for dredging activities of -3 to +21 days. Most coral species in the Northern Caribbean spawn during the months of July-September, some species have a wider season (see paragraph 6.2). It is recommended to concentrate dredging activities in the 5 month period of December 1st to April 30th. Since this window coincides with the period of cool seawater temperatures, using this window would generally reduce stress in corals.

The **application of silt screens** is most successful in situations with hard structures at 3 borders (breakwaters, shoreline etc.: Radermacher, 2013; De Wilde, 1995; Yasui et al., 1999). This situation occurs when construction of the breakwater is completed and dredging commences.
In "perfect" cases, i.e. no currents, no waves and no tide, retention rates by silt screens can be as high as 80 to 90%. Deviation from these perfect conditions will decrease the efficiency. Currents above 0.5 m/s, waves above 1 m and high tidal range (above 3 m), will result in retention factors of 25 to 40% only (Laboyrie et al, 2018). Since currents and tidal action inside the breakwater structure are negligible and waves are expected to be well below 1 meter for the most of the time, we assume an efficiency of 40% for a combined (or double) screen type (see figure 6.10).

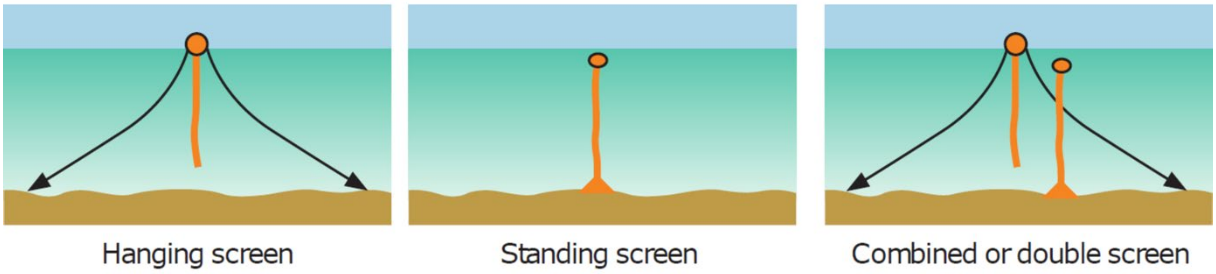

Figure 6.10: Types of silt screens (from Laboyrie et al, 2018; black arrows represent anchors)

Tables 6.18 and 6.19 present the values for SSC and sediment deposition in case of using a closed bucket for the backhoe dredger. No impact is expected with respect to average SSC, peak SSC and deposition, except for patch reef 2 during phase 2 of dredging (minor impact from deposition).

Since the modelling of SSC and sediment deposition on the reefs nearer to the source than 150-200m can only be done with limited accuracy (see also previous paragraph), the results with respect to patch reef 2 must be treated with caution. In addition to this, it is noted that patch reef 2 is largely in the high-risk zone and that protected corals are planned to be relocated from this area.

Based on the results described in this section, mitigated impact from SSC and sedimentation by dredging is considered "moderate" for patch reef 2 and "low" for the other patch reefs, particularly outside the high-risk zone.

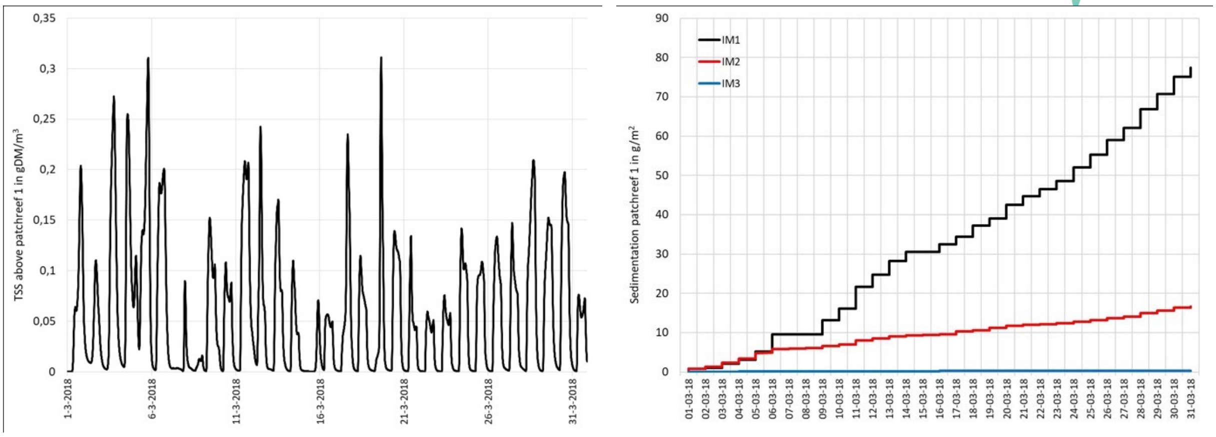

Figure 6.11: Total suspended solids concentration (TSS or SSC in mg/l, left) and deposition (g/m2, right) at patch reef 1 during 1 month of dredging (phase 2).

Table 6.16 Excess SSC expressed as average and percentage of time > 1 mg/l and > 2 mg/l at 4 nearby patch reefs and dive site (Giles Quarter/Greer Gut, **unmitigated**)

Activity	Unit	Patch reef 1	Patch reef 2	Patch reef 3	Patch reef 4	Giles Q./GG
Dredging phase 1	SSC average mg/l	0,0	0,2	0,0	0,0	0,0
	% of time >1 mg/l	0,0	**1,1**	0,0	0,0	0,0
	% of time >2 mg/l	0,0	0,0	0,0	0,0	0,0
Dredging phase 2	SSC average mg/l	0,1	0,5	0,0	0,0	0,0
	% of time >1 mg/l	0,0	**11,4**	0,0	0,0	0,0
	% of time >2 mg/l	0,0	**0,5**	0,0	0,0	0,0

Color indication: no color = no impact; green=slight impact; yellow=minor impact; orange=moderate impact; red= major impact

Table 6.17 Excess sediment deposition (all fractions: 63µm-20µm, 20µm-6µm, < 6µm) during construction at 4 nearby patch reefs and dive site (Giles Quarter/Greer Gut, **unmitigated)**

Activity	Unit	Patch reef 1	Patch reef 2	Patch reef 3	Patch reef 4	Giles Q./GG
Dredging phase 1						
Average daily deposition	mg cm^{-2} day^{-1}	0,0	0,2	0,0	0,0	0,0
Maximum daily deposition	mg cm^{-2} day^{-1}	0,1	0,5	0,2	0,2	0,1
Dredging phase 2						
Average daily deposition	mg cm^{-2} day^{-1}	0,3	**2,4**	0,1	0,1	0,1
Maximum daily deposition	mg cm^{-2} day^{-1}	0,6	5,8	1,3	1,4	0,7

Color indication: no color = no impact; green=slight impact; yellow=minor impact; orange=moderate impact; red= major impact

Table 6.18 Excess SSC expressed as average and percentage of time > 1 mg/l and > 2 mg/l at 4 nearby patch reefs and dive site (Giles Quarter/Greer Gut, **mitigated: closed bucket 50% reduction**)

Activity	Unit	Patch reef 1	Patch reef 2	Patch reef 3	Patch reef 4	Giles Q./GG
Dredging phase 1	SSC average mg/l	0,0	0,1	0,0	0,0	0,0
	% of time >1 mg/l	0,0	0,0	0,0	0,0	0,0
	% of time >2 mg/l	0,0	0,0	0,0	0,0	0,0
Dredging phase 2	SSC average mg/l	0,0	0,2	0,0	0,0	0,0
	% of time >1 mg/l	0,0	0,0	0,0	0,0	0,0
	% of time >2 mg/l	0,0	0,0	0,0	0,0	0,0

Color indication: no color = no impact; green=slight impact; yellow=minor impact; orange=moderate impact; red= major impact

Table 6.19 Excess sediment deposition (all fractions: 63µm-20µm, 20µm-6µm, < 6µm) during construction at 4 nearby patch reefs and dive site (Giles Quarter/Greer Gut, **mitigated: closed bucket 50% reduction**)

Activity	Unit	Patch reef 1	Patch reef 2	Patch reef 3	Patch reef 4	Giles Q./GG
Dredging phase 1						
Average daily deposition	mg cm^{-2} day^{-1}	0,0	0,1	0,0	0,0	0,0
Maximum daily deposition	mg cm^{-2} day^{-1}	0,0	0,3	0,1	0,1	0,1
Dredging phase 2						
Average daily deposition	mg cm^{-2} day^{-1}	0,2	1,2	0,1	0,0	0,1
Maximum daily deposition	mg cm^{-2} day^{-1}	0,3	2,9	0,7	0,7	0,4

Color indication: no color = no impact; green=slight impact; yellow=minor impact; orange=moderate impact; red= major impact

6.8 Impacts in deeper waters

If more sediments are excavated than needed in the project, it may be necessary to dispose of the sediments in open sea. The location that has been used in the past is indicated in figure 6.11. This location was selected by SCF to balance burden for contractors and impact on maritime flora and fauna (coordinates: 17° 39.215'N 63° 16.194'W, see figure 6.11).

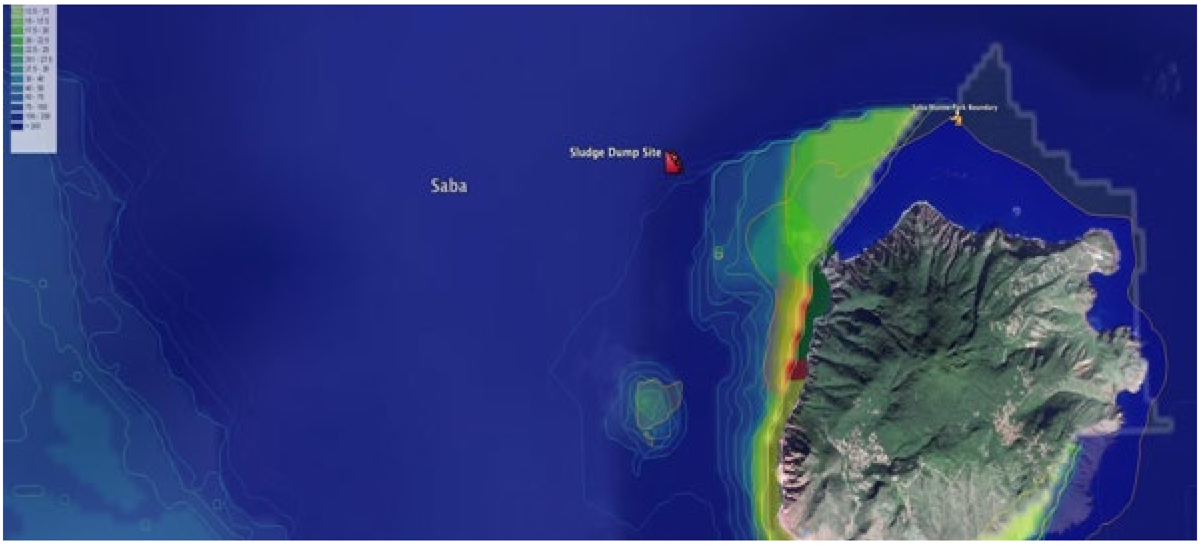

Figure 6.11: Location where excess sediments have been deposited in deep waters

In this discharge area, the depth of the seafloor is approximately 200 meters. The main impacts from the discharge will be a local and temporal plume of fine sediments, and the sinking of larger particles (sand, gravel, stones) to the seafloor. The exact impacts cannot be adequately assessed because of lack of information about sea life in this area (pelagic and benthic). It is unlikely however, that any biodiverse marine ecosystem is present in this area. The impact is qualified as "low".

6.9 Sensitivity analysis

A sensitivity analysis on current velocity has been carried out for patch reef 1, which is -when excluding patch reef 2 and 4- the next critical reef. Patch reefs 2 and 4 were not selected because of their close proximity to the source. Patch reef 2 is located in the high-risk zone and protected corals will be removed from the largest part of the patch reef. Impacts on patch reef 4 can effectively mitigated by stopping the work in construction phase 2.1.

The sensitivity analysis for patch reef 1 was carried out with a scenario of an average velocity of 6 cm/s (-50%, very low) and 16 cm/s (+50%, relatively high), for construction phase 2.1 and dredging phase 2. The analysis points out that suspended solids concentration (SSC) and deposition increase by a factor of maximally 30% (deposition) to maximally 48% (average SSC) in the low current scenario, as

compared to the 11 cm/s scenario (see table 6.20 and annex 11). In the high current scenario both suspended solids concentrations (SSC) and sediment deposition are 20 to 30% lower.
Peak concentrations do not exceed 1 mg/l at reef 1 and therefore the percentage of time in which 1, 2 or 5 mg/l is exceeded is zero in all cases.
From these results it can be concluded that also in the scenario with (very) low current velocities, impacts are not likely to exceed any critical values, even more certainly when impact mitigation is in place.

Table 6.20: Sensitivity analysis impacts at reef 1 for 2 scenarios (construction phase 2.1 and dredging phase 2). Increase/decrease relative to 11 cm/s current velocity

Average current velocity/ scenario	**Average SSC during daytime**	**Peak SSC (% of time above 2 mg/l)**	**Deposition**
6 cm/s – construction phase 2.1	43% higher	no significant impact, maximum excess value at reef 1 is < 1 mg/l	maximally 9% higher
6 cm/s – dredging phase 2	48% higher	no significant impact, maximum excess value at reef 1 is < 1 mg/l	maximally 30% higher
16 cm/s – construction phase 2.1	25% lower	no significant impact, maximum excess value at reef 1 is < 1 mg/l	29% lower
16 cm/s – dredging phase 2	20% lower	no significant impact, maximum excess value at reef 1 is < 1 mg/l	23% lower

7 Other impacts

7.1 Terrestrial environment

7.1.1 Disturbance by noise and vibrations due to construction of breakwater

The three possible options for construction of the breakwater (berm, caisson and cofferdam breakwater) differ highly in impact by noise and vibrations. The construction of a cofferdam breakwater depends on impact piling. The piles needed for construction are probably more than 1 meter in diameter, which implies that relatively high-power equipment needs to be deployed. The other two construction types will cause significantly less noise impact.

The protected Brown pelican and the important bird species red-billed tropic bird[1] have been observed in the project area. Red-billed tropic bird mainly in the late afternoon and night period. Red-billed tropic birds have breeding colonies just north of the projected harbor, at altitudes from 50-200 meters: the colony of St. Johns Cliffs is most nearby and consists of 42-89 birds (Boeken and Leopold, 2020).
Typically, for red-billed tropic bird noise will be less impactful when human activities are kept at a distance from the nesting areas. This would be the case for "normal" construction activities at the coastline and at sea level (pers. comm. dr. Mardik Leopold Wageningen University and Research). For percussive piling this conclusion cannot be drawn beforehand. This process produces periodic impulsive noise of very high intensity. This chronic[2] noise can have clear deleterious consequences on resident or breeding birds individually, while reductions in population density with proximity to noise sources are also well documented (Wright et al, 2015). Direct effects of chronic noise exposure include hearing loss, increased production of stress hormones and hypertension. Indirect effects include the masking of acoustic signals such as calls and sounds which may otherwise lead to alert behavior.

Deleterious effects of chronic noise exposure have been suggested to begin at levels as low as 55–60 dB(A) (Dooling & Popper 2007). At noise levels above 70 dB(A) most birds will choose an energetically costly flight response (Wright et al 2013). Expected noise levels and vibrations at the location of the bird colony have not been determined quantitatively in this EIA. If the cofferdam structure is eventually the preferred option, this quantitative assessment needs to be carried out. In such an assessment the occurrence of vibrations should be included, since low-frequency noise is a significant source of vibrations.

For most other (terrestrial) birds a general guideline may apply, namely, that they can adapt behaviorally and avoid the areas with highest noise (Ortega, 2012).

The unmitigated impact by the construction of a berm breakwater or a caisson type breakwater on the colony of red-billed tropicbird is considered "moderate-low". In case of pile driving (cofferdam breakwater) noise impacts to this colony is classified as "possibly severe".

[1] The red-billed tropic bird is considered to be a least-concern species according to the International Union for Conservation of Nature (IUCN), but populations are declining. In some places, such as Brazil and Mexico, this bird is considered to be threatened

[2] High noise levels and vibrations because of pile driving will continue for 4 months

Mitigating measures

In case of selection of the berm breakwater or the caisson breakwater, no mitigating measures are proposed to reduce noise during this process. In case of selection of a cofferdam construction, involving noise-intense pile driving, a **quantitative acoustic assessment** should be carried out. Depending on the outcome of this assessment in relation to thresholds (see previous section), mitigating measures can be:

- using **vibro-driving** instead of pile driving: vibro-driving is continuous in character and usually of a much lower sound level than impact piling.
- If a hydraulic impact pile driver is being used instead, methods to reduce noise are: using a **contact damper** between the pile and the hammer to absorb part of the energy, and prolonging the contact time of the hammer.
- a **soft start** procedure may be applied, in which the piling impact energy is gradually increased over a 10-minute time period. This creates a chance for birds (brown pelican, red-billed tropic bird) to move away from the source of noise. The soft start procedure should also be used after long breaks of more than 30 minutes in piling activity
- **Construction activities** take place **between 08.00**, the time the red-billed tropicbird fly to open sea, **and 16.00**, the time of day that the birds return to their nesting and roosting locations. This measure may be less effective with respect to chicks;
- Construction activities take place in the period **excluding December-March**, when there is a peak in roosting behaviour in the colony of red-billed tropic bird[1];
- In order to determine if any other adaptive measure is necessary, an ornithologist (bird expert) needs to **monitor the behavior** of the red-billed tropic birds for signs of stress.

Avoiding breeding periods is useful for the majority of birds living in the area (March-June), but for the red-billed tropic bird this is not possible, these birds are breeding year-round (Boeken, 2016). Brown pelican are not breeding on Saba.

The mitigated impact from pile driving to the bird colony of red-billed tropic birds is classified as “possibly severe”, since there is no quantitative information on the anticipated noise levels at the location of the colony of red-billed tropic bird. For the construction of a berm breakwater or a caisson type breakwater, no noise-mitigating measures are proposed; the impacts remain ‘moderate-low”.

7.1.2 Disturbance by construction of gabions

The construction of the series of gabion weirs will produce both noise and visual disturbance by the presence and activities of the workforce. Various studies, as summarized in the report of Cutts et al. (2009), indicate that anthropogenic noise is an important source of disturbance to waterfowl and also the presence of persons/machines causes disturbance to waterfowl. According to Cutts et al., construction noise should be restricted to below 70dB(A). Possible sudden irregular noise above 50dB(A) should be avoided.

During the construction phase, manual labour and activities by small machines are taking place between the 30- and 75-meters contours, which is relatively near the nesting sites. These activities can therefore significantly impact the colony of red-billed tropic birds, nesting in the middle and higher sections of the hill (50-200m altitude).

Species differ drastically in their sensitivity to human disturbance. For burrow-nesting seabirds such as shearwaters, puffins and auklets, human disturbance such as visitation has a limited effect on the

[1] According to Saba Conservation Foundation a peak in roosting behavior is observed during the months of December-March

breeding adults, as they tend to be away foraging at sea during the day. For the chicks remaining at the nest however, the disturbance can cause stress, potentially leading to impaired development (Albores-Barajas et al, 2014). Adult red-billed tropic birds have similar feeding patterns and comparable risks can be expected.

The unmitigated impact from the construction of the weirs (at the 30 to 50 meters contour) is classified as “severe”. Without any mitigating measures, there is a risk that a part of the birds leaves their nesting sites.

Mitigating measures

For the construction of the weirs the following mitigating measures should be implemented:

- **construction activities above the 50 meters contour should be undertaken with much care and under supervision of an ornithologist, whose main task is to monitor the impact of the activities on the red-billed tropic birds and in case of significant impact advise on mitigation measures.**
- **using of low-noise equipment**;
- **Construction activities take place between 08.00 and 16.00 only** (see mitigating measures cofferdam construction);
- The **period of December-March** should be **avoided** (see paragraph 7.1.1);

The mitigated impact from the construction of the weirs is classified as “significant”.

7.1.3 Landscape degradation

The current landscape in the area which consists of gently sloping hillsides with grass and shrub vegetation will be significantly changed by the harbor development, and this change is irreversible. The harbor, roads, buildings and drainage structures will change the landscape.
The unmitigated impact on landscape, of the harbor project as a whole can therefore be qualified as “significant”.

Mitigating measures

The series of small gabion weirs can be constructed out of local materials. This and the limited height of 2 meters will make the weirs blend into the landscape.
Since these mitigating measures only concern a small part of the whole harbor development, impacts to landscape after mitigation are still qualified as “significant”.

7.1.4 Future development

Two important side effects are expected, related to the proposed harbor construction, (1) access to private lands that were relatively inaccessible before the project, and (2) a steep increase of the value of those private lands.
This development will in turn lead to a strong rise in property values and a stimulus for development of these areas. If this development actually takes place this in turn may lead to a need for a shorter access road to the area. In recent times such a link, which should connect the road between Windward Side and Sint John’s to the harbor area, has already been discussed in the public arena. Such future developments will lead to further losses of terrestrial and marine nature values and will change the area in an irreversible way. Unmitigated impact is considered “severe”.

Mitigating measures

The risk of unplanned development can be mitigated by a **zoning plan** or partial zoning plan for the area. Still, mitigated impact is categorized as “significant”.

7.2 Marine environment

7.2.1 Dust and contaminated run-off from construction site and lay down area

At the construction site and laydown area, a variety of construction materials will be stored: sand, cement, aggregates etc.
In case the choice is made for a caisson structure, the caissons themselves will probably be constructed off-island. Some concrete work may still be done on the island however. This may include (part of) the concrete deck and the wave wall on top of the structure. This can be constructed as prefab elements, cast in the construction laydown area and placed on the caissons, or cast in-situ on top of the caissons using formwork.
During periods of high winds particulate material will become airborne and will be blown to open sea. During rainy periods, runoff water from the construction site may contain fine particles (sand, cement). This runoff flushes to open sea and may lead to water quality impacts (specifically higher concentrations of suspended solids) and sedimentation. Since the area of construction is large (1,2 ha) and the construction period is relatively long (more than 2 years), this impact is considered "significant".

Mitigation measures

Impacts by wind dispersion of particulates will be mitigated by placing **wind screens (closed fences)** at the construction site.
Mitigation of sediment loaded runoff takes place by **diverting all storm water** from the storage areas and by installing **retaining walls or bunds** at the lower side of the construction site to prevent run-off flushing to sea (see also paragraph 6.5). Additionally, the area needs to be **kept clean at all times**.
The contractor will have to prepare a **Storm Water Pollution Prevention Plan (SWPPP)**.
The mitigated impacts are considered "moderate".

7.2.2 Altered currents and wave exposure

Figure 7.1 shows areas near the breakwater where average current velocities are reduced by more than 25%, because of the presence of this new structure. In these areas, just east and west of the projected breakwater, benthos (organisms that live on the seafloor), will suffer from less water circulation. Less circulation will result in more sediment deposition and poorer water qualities.
Another anticipated impact by altered currents and wave action is reduced effectiveness of passive sediment rejection in different species of corals. Especially branched corals, such as *Acropora palmata*, depend on passive rejection (Erftemeijer, 2012). Altered waves are expected mainly west of the breakwater.
Corals impacted by reduced current velocity and wave action are located in the area of the footprint and high-risk zone for a large part (see also figures 5.16 and 5.17). Protected corals of the Orbicella and Acropora genera will be removed from this zone to a safer area.
The area just west of the breakwater, which is currently the habitat of a cluster of *A. palmata* (see figure 5.17) will be unsuitable for this species in the future, because of the combination of a new sediment source (outlet from weirs), reduced current and reduced wave-action.
Non-protected corals and benthos will remain in the area and will be impacted. Because of the low cover of corals (1,6% in this area) and the removal of protected corals, the impact is qualified as "moderate". Impacts cannot be mitigated.

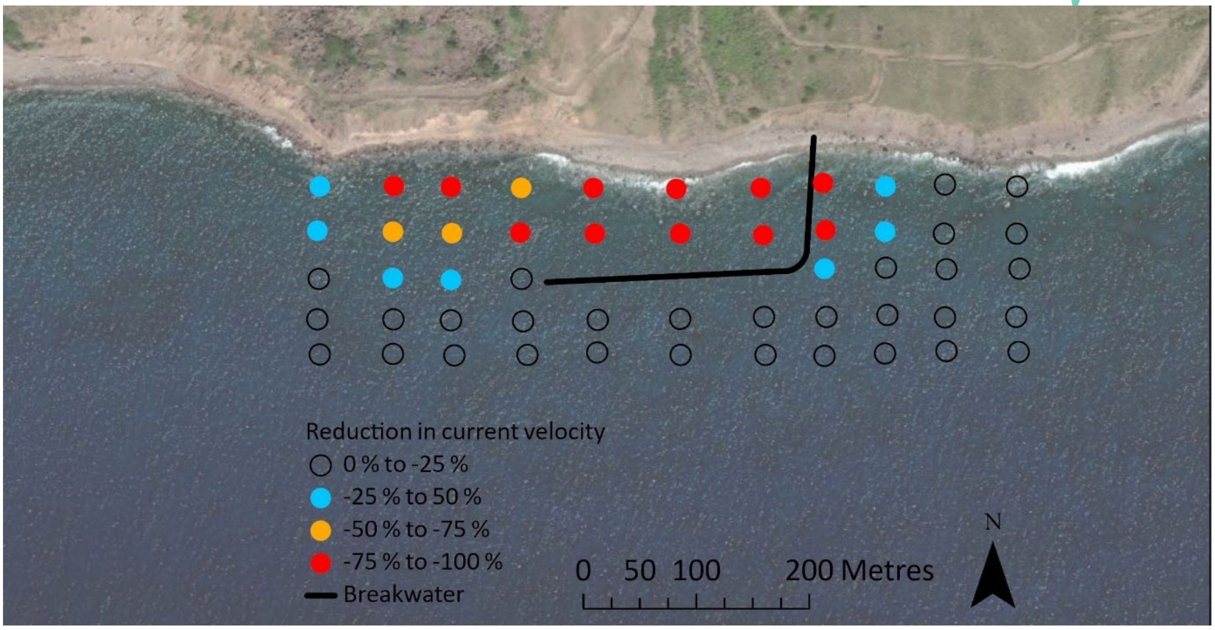

Figure 7.1: Areas with reduced current velocities

7.2.3 Noise, vibrations and disturbance

Construction of a caisson type breakwater or a berm breakwater will have limited underwater noise impacts. The construction of a cofferdam breakwater on the other hand, depends on pile driving, which is one of the strongest sources of underwater noise known and is likely to disrupt the behavior of marine mammals at ranges of many kilometers. Pile driving activities have the potential to induce hearing impairment in marine mammals at close range (Madsen et al. (2006).

Impact piling produces multiple pulses occurring at typical blow rates of 30 to 60 impacts per minute. Source levels underwater range from SEL 170–225 dB re 1 µPa^2·s for a single pulse, and peak levels from 190–245 dB re 1 µPa[1]. With repeated strikes the noise energy cumulates and may exceed the sound exposure guidelines for cetaceans (whales and dolphins), sea turtles and fish (Popper et al., 2014; Government of South Australia, 2012), especially when these organisms are close to the source of noise. Impact areas where behavioral responses can occur can be quite large (up to 25 km from source without impact mitigation, Arcadis, 2020).

Literature suggests that fish, turtles, diving birds and whales and dolphins can move away from a pile driving source (Popper et al., 2014; Government of South Australia, 2017) but if they do not, the result can be hearing loss[2] and barotrauma of internal organs (e.g. organs near swimming bladder). These impacts in individuals can be lethal.

While whales and dolphins are most vulnerable during calving and mating periods, in general it can be stated that all cetaceans are sensitive to noise and harming them at any age should be avoided (pers. comm. dr. M. Scheidat, Wageningen University and Research). Animals that are roaming over large areas are likely better able to avoid noise without major impacts on the population, then are residential animals. Some of the dolphin species present may be residents.

[1] Since piles used for the breakwater are >1m diameter, relatively high power equipment will be used and source levels will be in the higher ranges

[2] In cetaceans (whales and dolphins) 183 dB SEL re 1 µPa^2·s can lead to TTS (temporary noise induced hearing loss) and 215 dB SEL re 1 µPa^2·s can lead to PTS (permanent noise induced hearing loss). Source: Nehls, Betke, Eckelmann, & Ros, 2007. See also Annex 8

Popper et al (2014) differentiate fish in 3 groups which differ in sensitivity to noise: (1) fish with swim bladder involved in hearing (most sensitive), (2) fish with swim bladder not involved in hearing (medium sensitive) and (3) fish without swim bladders (least sensitive).
Specific data on sea turtles are lacking, but because of their rigid external anatomy, it is possible that sea turtles are better protected from pulsive sound effects such as pile driving (Popper at al., 2014). Sharks, because of the absence of a swim bladder are less vulnerable to underwater sound than fish with a swim bladder (Popper at al., 2014).

Diving bird species will also experience impacts by noise during pile driving. Species that have relatively long diving times (e.g. Audubon shearwater, Brown pelican) are more vulnerable than the species that have short diving times (e.g. Roseate tern, Red-billed tropicbird).

The unmitigated impact on fish, turtles, whales and dolphins is considered “moderate-low” in case of construction of a berm breakwater or a caisson type breakwater. Most species will be able to adapt behaviorally. In case of construction of a cofferdam breakwater, which involves piling for a period of 4 months, and a very large impact zone, noise-impacts are classified as “possibly severe”.

Mitigating measures

In case of selection of the berm breakwater or the caisson breakwater, no mitigating measures are needed to reduce noise during this process. In case of selection of a cofferdam construction, involving pile driving, a **quantitative acoustic assessment** should be carried out. Depending on the outcome of this assessment in relation to thresholds (see previous section), mitigating measures can be defined. These can be:

The use of **vibro-driving** instead of pile driving: vibro-driving is continuous in character and usually of a much lower sound level than impact piling. Typical source levels range from SPL 160–200 dB re 1 µPa, with most of the sound energy occurring between 100 Hz and 2 kHz.

If the hydraulic impact pile driver is being used, three methods could be used to reduce noise generation. (1) changing the **pile-toe shape** (to e.g. pointed) to reduce impact energy needed for vertical movement, (2) using a **contact damper** between the pile and the hammer to absorb part of the energy (this often means that more strikes are needed), and (3) **prolonging the contact time of the hammer**.

Breeding and calving periods of marine (diving) birds and marine mammals should be avoided as much as possible, however, exact information on these periods is not always available, e.g. for diving birds (Audubon shearwater). Exceptions are the calving and mating period of the humpback whale and minke whale (winter months until March) and the reproduction period of dolphins (summer months, FAO 1993).
It would be beneficial to the marine mammals if the pile driving was done during a period where little to no marine mammals are present in the area, but this may be a challenge if a 4 month period is needed. Following the information from chapter 4, the period from January through March should be avoided for whales, and the month of March should be avoided for dolphins. A relatively favorable period for construction would be the period from April to September. In this period however, much attention should be given to dolphins, that may be present during this period, especially during the summer months in which they are reproducing (see all other mitigating measures)[1].

[1] In balancing the importance of ecosystem components (whales and dolphins), it was noted that the most common whale (humpback whale) and the most common dolphin (bottlenose dolphin) are both rated “least concern” in the IUCN Red List

Acoustic deterrent devices (ADD): ADD's can be used to stimulate cetaceans to move out of the area prior to the commencement of loud noises.

Zoning and observation: An observation zone (5 km radius) and a shut-down zone (2 km radius) for protection of marine mammals should be installed (these zones can be amended based on the final choice of technology and acoustic impact study). In the observation zone, movement of marine mammals is monitored to determine whether they are approaching or entering the shut-down zone. When a marine mammal is sighted near the shut-down zone, **piling activities must be stopped** as soon as reasonably practical. The observations could be executed by deploying a **spotter vessel,** e.g. from Saba Conservation Foundation. Since weather conditions can influence sighting success, the simultaneous use of a **hydrophone** is recommended[1]. These devices are also more effective for deep diving species which typically have little surface time.

In case of impact driving, a **soft start** procedure may be applied, in which the piling impact energy is gradually increased over a 10 minute time period. This creates a chance for fish, diving birds (brown pelican), turtles, whales and dolphins to move away from the source of noise. The soft start procedure should also be used after long breaks of more than 30 minutes in piling activity.

In some occasions with high expected noise levels and likely presence of marine mammals, so-called bubble curtains can be used. A bubble curtain is a circular "sheet" of air bubbles produced around the pile. The difference in sound propagation between air and water results in noise reductions of 3 to 20 dB (Government of South Australia, 2012). The system is particularly effective when used with a sleeve (see annex 8) but is not practical in areas with relatively high currents.

Mitigated noise-impacts for construction of a cofferdam breakwater are qualified as "possibly severe". A quantitative noise assessment should point out which mitigating measures will be adequate. For construction of a berm breakwater or a caisson type breakwater, no noise-mitigating measures are proposed; the impacts remain "moderate-low".

7.2.4 Physical damage to corals by anchoring

According to the Saba Marine Park Management plan (1999), the zone in which construction of the projected harbor takes place is a Multi-purpose zone. In this zone, anchoring is not allowed in areas with coral growth (article 9 of Ordinance).
Working barges for materials and equipment need to be properly anchored in the project area. Anchor lines can be quite long (up to 250 meters), and they usually rise up from the seafloor under small angles. When an anchored barge is moving from one location to another, with the anchors still in place, the resulting movement of the anchor lines creates the risk of damage to corals and sponges.
Impacts from anchoring are related to construction (not to dredging, see next paragraph). Impacts depend on the chosen method for the construction of the breakwater. In case of a cofferdam structure, no or minimal anchoring is required. Most piles are driven with equipment that can reach from land. Piles that have already been placed can function as fixed anchors.
For the caisson structure anchoring for positioning of caissons is needed. For the berm breakwater anchoring is needed as well, for positioning of barges, especially if rocks are being supplied by sea transport.
If anchoring takes place unmitigated, impacts can be expected in the patch reefs which are located at distances of less than 150 meters from the footprint. Impacts are therefore appraised as "possibly severe" (berm breakwater, caisson structure) to "low" (cofferdam structure).

[1] A hydrophone is especially useful for listening to the presence of deep divers (e.g. sperm whale).

Mitigating measures

For anchoring a permit by the Executive Council is required (see chapter 2). **No anchoring** should be allowed **outside the high-risk zone** and -if this is not possible- no anchoring should be allowed **in, near, or over the patch reefs.**

As a preventive measure, a detailed **anchoring plan**, with 3D representation of anchor lines above the reefs, which demonstrates no damage, needs to be **approved and enforced** by the Government of Saba (Harbor Master, Public Works) and the Ministry of I&W/Rijkswaterstaat.
The mitigated impacts are considered "moderate-low".

7.2.5 Physical damage by using spuds (dredging)

Impacts by use of spuds of dredging vessels are considered "low" because the damage is limited to the areas of dredging (where all benthos will be removed).

7.3 Overall comparison of impacts of three types of breakwaters

Table 7.1 presents an overview of impacts from the three breakwater alternatives: a berm breakwater (base case), a caisson structure and a cofferdam.

Table 7.1: Comparison of impacts 3 breakwater types (after impact mitigation)

	Berm breakwater	Caisson	Cofferdam
Footprint area Footprint width	13.000 m2 40m wide	7.500 m2 25m wide	4.000 m2 15m wide
Relocation of protected corals (colonies)	246	200	144
Sedimentation	Moderate	Less than berm breakwater	Less than berm breakwater
Noise above water Noise underwater	Moderate-low Moderate-low	Moderate-low Moderate-low	Possibly severe Possibly severe
Excess material, to be disposed of at sea	No	Low	Low
Anchoring/damage	Moderate-low	Moderate-low	Low

From an ecological point of view, a caisson structure for the breakwater is the preferred option, because (1) it results in a smaller footprint than the base case, (2) it results in the relocation of less protected corals compared to the base case and (3) it results in acceptable noise levels for the colony of red-billed tropic bird (42-89 birds at St. Johns Cliffs) and for marine fauna, including sea mammals.

The cofferdam construction-method will create more noise (underwater and above water) because of a period of 4 months of intensive pile driving. If this method is preferred from a viewpoint of harbor construction, a quantitative noise assessment is needed (both terrestrial and marine), to demonstrate that disturbance will remain at acceptable levels.

7.4 Attraction of unwanted species

Globally, seabird populations are under threat from cats and (introduced) black and brown rats, raiding nests for eggs and young (Birdlife International, 2021). This is certainly also the case for red-billed tropic bird on Saba (Boeken, 2016). A harbor development, like any development may introduce these species in the currently relatively undisturbed area. More people in the area, will lead to more food (e.g. from waste) for rats and cats (Ogan and Jurek, 1997). Stray cats have large home ranges, up to several kilometers. Like rats, they can be a severe problem for the colony of red-billed tropicbird (pers. comm. dr. M. Leopold). This impact is qualified as “significant”.

Impact mitigation

Culling of rats and (stray) cats is the usual response to high numbers of stray cats and rats. According to literature effectivity is uncertain. Mitigated impact is qualified as “unknown”.

7.5 Positive impacts

Some environmental and ecological impacts from the construction of the harbour can be regarded as positive. For instance, the construction of the gabion weirs will slow down the water flow. Water will infiltrate will become available as groundwater for longer periods in the lower areas, instead of being discharged into the sea.

On the longer term, the road construction has the potential to improve the situation with respect to erosion and sedimentation, when formerly eroded slopes will be stabilized and revegetated (see chapter 6 of this report).

8 Overview of impacts

8.1 Overview

Table 8.1 presents an overview of the most important impacts per subproject of the harbor construction, including impact mitigation and resulting severity of impact. With respect to sedimentation, it is important to mention that all subprojects causing sedimentation will be carried out sequentially, so that cumulative impacts are not likely.

Table 8.1: Overview impacts harbor construction and impact mitigation

Impact type	Impact/risk	Severity impact unmitigated	Mitigating or compensating measure	Severity impact mitigated (*)
Footprint access road	New parts of road and widening of current road: 20.000m2 of which 7.000m2 vegetated; loss of vegetation mainly grass and several mature trees (3)	Significant	Avoid cutting trees, replant trees, stabilizing and revegetation of slopes. Leave small water catchment intact	Significant, subs-tantial part of footprint lost irreversibly; revegetation towards diverse plant community takes time and can occur in part of the footprint only
Footprint weirs + path workforce	Ecological loss in footprint weirs (615m2, all vegetated, fauna of conservation importance, Important Bird Area) 450 m of path for workforce (1 m width)	Significant	Avoid cutting trees, replant trees, execute detailed vegetation survey of path and protect or replant rare species	Low
Footprint harbor area landside	Ecological loss in footprint area harbor of vegetated land (14.000m2, of which 9.000m2 vegetated, and in Important Bird Area-IBA (0-400m from coast), habitat for seabirds)	Possibly severe	Trees left intact where possible; replanting of trees; planting of young trees of native species in harbor area	Significant, most of the footprint will be lost irreversibly. Area in a fair natural state
Footprint marine infrastructure (and high-risk area)	Benthic fauna lost in footprint area: 32.000 m2 Severe impacts in high-risk zone (total area of footprint and high-risk zone: 90.000m2). Protected corals (246 colonies) will be relocated in base case (berm breakwater)	Severe	Relocation of colonies of protected corals; enhanced settlement of other coral (juvenile, without protection status); armour rock for breakwater suitable for coral settlement	Significant, loss of habitat for shallow water corals. Anticipated loss of 35% of colonies of protected species (86 colonies) of protected coral species after relocation

				Regrowth of corals and reefs takes much time
Sedimentation from construction of access road	Access road needs to be widened from 4-5 m to 7-8 m; further benching of hillside required; deterioration of water quality, impact on sensitive corals	Severe (note: current situation with respect to erosion is also severe)	Paving of roads; stabilizing of all profiled slopes with netting, steel mesh, anchors, biodegra-dable mats, or with confinement methods; active revegetation; adequate water drainage from road. Measures are effective: 75% reduction of erosion after slope stabilization and 99% after restoration of vegetation)	Short term: significant (roads will be paved after 1,5 years) Long term: low impact (positive compared to current situation)
Sedimentation by construction of weirs	Slow down water flow and allow water to infiltrate; reduction of run-off, however quality of run-off unknown (may be poorer than current situation); discharge in low-current area with presence of *Acropora palmata.* Seagrass field at >600 meters distance	Moderate (note: majority of impacted *A. palmata* are already in footprint and need to be removed); seagrass bed probably outside impact zone	Revegetation); Sand catchment box has limited effect;	Short term: Moderate-low Long term: Possibly positive
Sedimentation from levelling of harbor area	Large scale groundworks (1,2 ha). Areas can be unused and unvegetated for a long time, promoting erosion and sedimentation	Severe	Gabions, including gutters to the discharge location, must be constructed before levelling of area can take place; temporal revegetation; a system of temporary bunds or gabions constructed to hold and slow down runoff	Short term: significant Long term: moderate, but depending on ratio paved/ unpaved and vegetated/unvege tated
Sedimentation by construction of breakwater (base case, bund breakwater)	Impact on water quality (TSS) and sediment deposition. Minor impact at reef 2 during phase 2.5 and slight impact at reef 4 during phase 2.1. Data should be used with caution for reefs at short distance (reef 2 and 4)	Significant for patch reefs 2 and 4. Moderate for other reefs	Screening of aggre-gates, maximum of 5% of fines (instead of 33%); dis-continuation of construction during current reversal; monitoring (water quality, coral health) and adapt as needed	Moderate for patch reef 2, low for all other reefs

Sedimentation from construction of landside quays and RoRo revetment	Backfilling of landside quays in dry space, placement of 1000m3 of quarry run for RoRo revetment	Low	Screening of aggre-gates, maximum of 5% of fines	Insignificant
Sedimentation from dredging	Impact on water quality (TSS) and sediment deposition. Relatively high values (causing minor impact) for reef 2. Data should be used with caution for reefs at short distance (reef 2)	Significant for patch reef 2 Moderate for other reefs	Closed buckets for BHD (50% less fines in suspension); prevent over-dredging; temporarily relocate dredge activity if necessary; no dredging close to spawning season; silt screens; removing sediments from benthos	Moderate for patch reef 2 Low for other reefs
Sediment discharge in open sea		Low	N.A.	Low
Noise (terrestrial) by breakwater construction	Main risk: noise impact on colony of red-billed tropic bird by pile driving (4 months)	Construction of berm breakwater or caisson breakwater: moderate-low. Noise from piling (cofferdam): possibly severe	Construction of berm breakwater or caisson breakwater: N.A. Pile driving/cofferdam: Quantitative noise assessment. Noise reduction of pile driving	Construction of berm breakwater or caisson breakwater: moderate-low. Noise from piling: possibly severe.
Presence of workforce and noise (terrestrial) by construction of weirs	Disturbance of colony by presence of workforce and noise production	Work takes place near red-billed tropic bird colony: severe	activities above the 50 meters contour should be undertaken under supervision of ornithologist; Construction work for weirs between 08.00 and 16.00; period of December-March	Disturbance by weirs construction: Significant
Landscape degradation	Landscape degradation by harbor development as a whole	Significant	Stabilizing and revegetation of slopes of weirs	Significant
Future development	Loss of nature and landscape	Severe	(Partial) zoning plan	Significant
Dust and contaminated runoff from construction site	Flux of dust and sediment loaded runoff to sea during high winds and storms	Significant	Fences, storm water diversion, bunds, cleaning, Storm Water Pollution Prevention Plan (SWPPP)	Moderate
Altered currents and wave action	Reduced currents and wave action, less circulation, deterioration of water	Moderate	N.A.	Moderate

	quality in direct vicinity of breakwater. Impacts on corals			
Underwater noise	Noise impact, mainly on fish, turtles, marine mammals	Construction of berm breakwater or caisson breakwater: moderate-low. Noise from piling (cofferdam): possibly severe	Construction of berm breakwater or caisson breakwater: N.A. Pile driving (cofferdam): quantitative noise assessment; noise reduction of pile driving; avoiding reproduction periods; zoning and stopping of pile driving when sea mammals approach	Construction of berm breakwater or caisson breakwater: moderate-low. Noise from piling: possibly severe.
Anchoring	Physical damage to corals and other benthos	Anchoring: Possibly severe (berm breakwa-ter, caisson); Low (cofferdam)	Zoning of anchoring; anchoring plan (permit)	Moderate-low (berm breakwater, caisson) Low (cofferdam)
Use of spuds (dredging barges)	Physical damage to corals and other benthos	Use of spuds: Low (limited to areas of dredging)	N.A.	Low (limited to areas of dredging)
Attraction of unwanted species	Like any development the development of a harbor can lead to the introduction of unwanted species in the area (rats, cats). This would harm the colony of red-billed tropicbird	Significant	Culling of rats and (stray) cats	Unknown
Positive impacts	The construction of the gabion weirs will slow down the water flow. Water will infiltrate and will become available as groundwater for longer periods in the lower areas	Positive	N.A.	Positive

8.2 Impacts on protected species

Currently, there is no specific island legislation for the protection of threatened and valued species on Saba. This legislation is still in development. On the national level however, a number of species are protected through the process of dynamic reference of international conventions in the National Law on principles of nature management[1]. These species are: all sea turtles, sharks and whales and dolphins that live in Saban waters, 3 bird species (Brown Pelican, Audubon shearwater and the Roseate tern) and 4 coral species (*Acropora palmata, Acropora cervicornis, Montastraea annularis* and *Montastraea faveolata)*.

[1] "Wet grondslagen natuurbeheer": The most relevant international conventions cited are: Cartagena Convention and SPAW Protocol, and the Convention for the Protection of Migrating species (CMS)

Most of the diving bird species will experience impacts by noise during pile driving. Species that live underwater (fish, sea turtles, sea mammals) or have relatively long diving times (e.g. Audubon shearwater, Brown pelican) are more vulnerable than the species that live above water and have short diving times (e.g. Roseate tern, Red-billed tropicbird). Sea turtles and sharks (which are lacking swimming bladders) are considered less vulnerable than marine mammals.
For protected corals the most important impacts are: relocation from the footprint area to a safer area with an estimated 70% chance of survival, and sedimentation.

Table 8.2 summarizes the most important risks for protected species, their sensitivity and the impact mitigation.

Table 8.2: Risks and impact mitigation protected fauna species

Protected Species	**Risk, sensitivity**	**Mitigation**
Green turtle, Hawksbill turtle	Moderately sensitive to noise, able to avoid noise loads (*)	Soft start pile driving, vibro-driving (**)
Whales and dolphins	Sensitive to noise, able to avoid noise loads (*)	Soft start, zoning, observation team, stopping procedure, avoid pile driving during calving period (January-March for whales and summer for dolphins), acoustic deterrent device (ADD) (**)
Whale shark and other sharks	Moderately sensitive to noise (lacking a swimming bladder), able to avoid noise loads (*)	Soft start pile driving, vibro-driving (**)
Brown pelican Audubon's shearwater	Sensitive to noise, swimming underwater[1]; able to avoid noise loads (*)	Soft start pile driving, vibro-driving (**)
Roseate tern Red-billed tropicbird[2]	Relatively shallow divers[3], medium risk (*)	Soft start pile driving, vibro-driving (**)
Corals: *Acropora palmata, A. cervicornis, Montastraea annularis* and *M. faveolata*	Corals need to be removed from footprint; Corals are sensitive to sedimentation	Relocation of protected corals. Slope stabilization and revegetation (land side construction), screening of aggregates (marine construction), closed dredging buckets and silt screens (dredging)

(*) Risks exist in case of choice for cofferdam breakwater
(**) Final measures depending on quantitative acoustic assessment

[1] Source: Guide to North American Birds
[2] Strictly speaking not a protected bird however criterion species for IBA designation
[3] Source: Guide to North American Birds

9 Stakeholder and expert consultation

Stakeholder consultation took place in two stages:

- Stage 1: Presentation of main features of project. During this stage, stakeholders could bring forward their priorities for the contents of the EIA.
- Stage 2: Presentation of results of EIA. During this phase stakeholders were able to react to the outcome of the EIA.

9.1 Presentation of main features of project

Dive operators Sea Saba and Saba Divers

The contours of the project were presented to Sea Saba and Saba Divers. Both dive shops expressed great concerns about the environmental impact of a new harbor and coastal development in general. These include:

a. the damage of corals (*Acropora palmata* and other) within harbor footprint.
b. the effect of removing/relocating these corals on other reefs (these colonies are also the gene pool responsible for successful reproduction on other reefs, e.g. Tent)
c. the loss of two or three dive sites (Giles Quarter Shallow, Greer Gut, Big Rock Market).
d. the risk of erosion and siltation during construction (dredging).
e. the risk of bringing in diseases with imported construction materials: sand, rocks, other.
f. pollution that comes with coastal development: fertilizers, trash, septic tanks, other.
g. pollution from the new road: oil, silt and other washing down to the sea.

Both dive shops expressed concerns about the proposed marina lay-out for Black Rocks Harbor (and Fort Bay Harbor). They think a calm marina with finger piers is an illusion and cannot work on Saba. There will be issues with maneuverability, wind, swell. Both dive operators stated that they rather stay on a mooring at Fort Bay. Even though Fort Bay Harbor is far from ideal, the dive operators are convinced that 'together we make it work'. Instead of building a new harbor, they suggest a number of improvements for Fort Bay Harbor, such as extension of the primary pier with 20 meters and a well maintained crane to lift boats out of the water quickly before a storm arrives. The dive operators think that a hurricane proof harbor is unrealistic.

Saba Conservation Foundation – Board members ([redacted] and [redacted]) and director ([redacted])

If the harbor plans at Black Rocks/Giles Quarter are pursued, there should be elaborate plans for mitigation and compensation. Saba has one of the oldest marine parks in the world. International organizations like Greenpeace should not get the impression that that the reefs get destroyed. More than the relocation of protected corals, the future development of the whole harbor area is worrisome. The dive sites near Black Rocks are not frequently used by the dive shops, but the Caribbean Explorer (a liveaboard diving ship) does use these sites.
The Fort Bay harbor was reconstructed many times after hurricanes. A new construction in Black Rocks may end this. It will be a good thing, as long as it is done well, with as little environmental impact as possible.
As a compensation measure, the Marine Environment Ordinance should be used to create a coastal buffer zone, to limit the risks of future coastal development. In addition, waste water should be managed all over the island and the BES Bouwbesluit (building regulations) should be enforced and/or supplemented.

It is emphasized that it is important to keep the discussion about the harbor open. Both those in favor of and those opposing the new harbor must be heard.

[redacted] (fisherman)

[redacted] thinks the majority of the fishermen agree that a new harbor should be built. He does not think the new harbor at Black Rocks will have a big environmental impact, because it is now a dead area overgrown with algae. Fifteen years ago there was much more (fire) coral, a lot of fish and other sea life. About 13-15 years ago the water suddenly turned green/brown with algae and bleaching of coral was visible.
Dive shops hardly ever use the dive sites close to Black Rocks. [redacted] agrees with the dive shops that there should be an easy way to get boats out of the water, and a proper ramp would be most useful.
The fishermen association wants to purchase a piece of land with a warehouse to do boat work. This warehouse could also be used to store boats during storms.

[redacted] (nature expert, independent stakeholder)

According to [redacted], Black Rocks is a better and more logical location for a harbor than Fort Bay. [redacted] believes that the construction of a harbor at this location will not have a major impact on the reef. There are of course risks during the construction phase, but measures can be taken to mitigate these. The Acropora-colonies should preferably be placed outside the area (preferably including the rock to which they are attached).
On land, it is not a vulnerable environment either, the vegetation is limited and relatively poor in species diversity. The same vegetation can be found both west and east of Black Rocks.
According to [redacted], further development of the area will not occur any time soon. Currently it is not an attractive place to live because of the wind, salt and lack of shelter.
The stone crusher is currently a major danger to the reef, due to the presence of a lot of loose material that ends up in the sea. Sedimentation in the area can be limited with the help of gabions (smaller rocks with vegetation in between, held together with chicken wire).
[redacted] thinks it is a good idea to set up a buffer zone where restrictions (no prohibitions) with regard to development apply, by means of the Marine Environment Ordinance. However, agriculture will always have to be possible. Some opposition is to be expected; keeping goats out of the buffer zone, for instance, will be very difficult.
Of course, everything must be done to limit the impact of the port, but it is an important development for Saba and sometimes you have to sacrifice something smaller.

[redacted] (Policy Advisor, Government)

The vision of the Public Entity of Saba is controlled, sustainable growth. Construction of a harbor at Black Rocks-Giles Quarter is compatible with this vision. This project will also be the start of the further development of this area. It is expected to happen within 5 years from now. In the past landowners have indicated that their wish is to develop the area (Cattle Plantation). [redacted] expects that 80% of the Saban people will not have an explicit opinion about the harbor development at Black Rocks: 10% will be in favor of a new harbor and 10% will be opposed. A public consultation will not be necessary.
Protected and other corals can probably be relocated to safer areas. Their safety should be guaranteed for the long term.
A compensation that may be considered is the definition of a coastal zone where only limited development and low impact development could be allowed and where erosion control measures will be carried out (e.g. through the Saba Marine Environment Ordinance).
The loss of 2 dive sites may be compensated by creating a spot for divers and snorkelers near the harbor, where they can work on coral (restoration or monitoring) projects.

Other suggestions for compensation by [redacted] are: reforestation of the location, establishment of a fund for coral reef conservation projects.

9.2 Presentation of EIA-results to stakeholders

Saba Conservation Foundation ([redacted]), [redacted] (Van-Hall-Larenstein)

For SCF it remains a concern that the new harbour will "take a piece out of the Saba Marine Park". In addition to this, SCF expects that in the terrestrial area rising property-prices will stimulate private developments such as construction of condominiums. Therefore adequate compensation is essential. Compensation by means of spatial planning and low impact development can be effective. Stimulated coral recruitment (not only limited to the protected corals) is another effective measure. According to SCF a "Coral Reproduction Centre" will be essential to realize this.

[redacted] adds to this that compensation can also be offered at the level of reef structures, e.g. complete artificial reefs in locations that are currently sandy bottoms. Opposite of Gary's Pond a good example of an artificial reef is present (100x30 meters, 5-10m below surface, rocks of 50-100cm): "Diadema City". The structure originated unintentionally when a breakwater was swallowed by the sea. In this artificial reef, *Diadema antillarum* is reproducing successfully (3-5 individuals per m2, 2000 specimens in total) and corals are recruiting abundantly. Especially the success of *Acropora cervicornis* is remarkable. There were quite some brain corals on the big boulders, but most suffer from stoney coral tissue loss disease (SCTLD) at the moment. *Porites porites* is another abundant coral species on the reef.

Fish densities and species richness seem to be very high, higher than on most other sites on Saba. Macroalgae cover and turf algae cover is extremely low compared to natural reefs, due to the Diadema grazing. Coral recruitment is relatively high, but coral cover is low. This might be the result of 1) the young age of the reef, 2) the grazing of the Diadema and 3) the shift of boulders during big storms.

The current pilot project for coral relocation indicates that the relocation success will be higher in Hole in the Corner, compared to Ladder Bay. The best timing for relocation is November-December, when water temperatures are cooling down.

Red-billed tropic bird are concentrated slightly West of St. John's. According to Saba Conservation Foundation a peak in roosting behavior of red-billed tropic bird is observed during the months of December-March.

[redacted] (Policy Advisor, Government)

[redacted] has no comments on the EIA. He does have a number of observations:

- Patch reef 1 will be in the apporach route of the new harbor. There is a good chance that on the long term impacts in that reef (emergency anchoring and pollution by ships), will lead to the disappearance of this patch reef. He assumes that this is not in the scope of the EIA which was confirmed by [redacted];
- [redacted] sees anchoring as a very serious risk. The mitigation measures (anchoring plan, enforcement of this) should have high priority;
- The proposed retention dams will probably experience sedimentation themselves and need to be excavated from time to time. It will propbably more effective to use a larger number of small retention dams (gabions);
- Revegetation should start as soon as possible. Government has a small budget (through the Netherlands) for revegetation projects;

* Uncontrolled development looms when land prices near the Black Rocks harbor start to rise. The Saba Government does not have many legal instruments to reduce the risk of uncontrolled development. One of the possibilities for Government is to purchase land.
* If a new road connection to Windward Side is considered there will be increased interest in developing the area of the "Cattle Plantation";
* A compensation measure proposed by [redacted] is to create an island wide zone of at least 50 meters from the sea shore, in which no development should take place at all, the main argument for which being climate change and guaranteeing safety. This could be implemented though the Saba Building Ordinance.

Sea Saba Diving Center ([redacted])

The main point brought forward by [redacted] and [redacted] is that the option of a cofferdam breakwater (piling and sheet piling) will have very serious noise impacts on marine fauna, not only on sea mammals but also on fish and sea turtles. The sea turtles are a great attraction for the divers visiting Saba and the noise impacts could seriously harm dive tourism. The turtles are present in the area between Fort Bay and Black Rocks. [redacted] and [redacted] are strongly in favor of a caisson structure, from which no serious noise impacts are to be expected.

A number of additional remarks were made:

* It is a possibility that the Audubon shearwater is a nocturnal bird and that it can be affected by strong lights during the night. This may be checked;
* Ladder Bay does not seem to be a good location for relocation of elkhorn coral. There was never a significant stand of this species in Ladder Bay;
* Red-billed tropic bird at Tent reef can be seen returning to land already before 16.00 in the afternoon

9.3 Expert consultation

On January 29, 2020, we consulted [redacted] (Wageningen University and Research) on possible impacts by harbor construction on nearby colonies of red-billed tropic bird. [redacted] indicated, that in his opinion the location of disturbance is important. If the (noise) disturbance is near the birds, there may a serious impacts for the colony. [redacted] indicates that activities for harbor construction would not pose a direct threat to the colonies nearby, as long as sufficient impact mitigating measures are taken and the activities remain near the coast. The birds are breeding at higher altitudes, always higher than 50 meters altitude.
[redacted] indicated that there other threats for the colonies of red-billed tropicbird. In particular the presence of stray cats and rats. It is probably these threats that decimated the population of red-billed tropicbird in several areas around Saba. Especially the population along Saba's south coast was declining for a period, but the species is reproducing again in this area.

On April 9, 2021, we consulted [redacted] (Wageningen University and Research) on presence of marine mammals, seasonality of this presence and reproduction.
[redacted] informed us that the current research on the Saba Bank and near Saba confirms that the two most common whale species in the waters near Saba are the humpback whale and the common minke whale. They are known to reproduce in the Caribbean waters in winter until March. Sperm whales are also known to be present, they probably live in the deeper waters, north of Saba. The most common dolphins are spinner dolphins and bottlenose dolphins. They are present year round and have their reproduction season in summer.
The season to avoid heavy construction (pile driving) is winter, not only because of adverse weather conditions, but because of the reproduction of the humpback whale and minke whale. If the summer season is included in the construction period, serious consideration has to be given to groups of dolphins which are likely to be mating and giving birth.

Observation zones and shut-down zones, acoustic deterrent devices (ADD) and soft start (for piling) may be effective measures to prevent damage to cetaceans. However, it is important to carry out a quantitative acoustic assessment to determine the propagation of noise in the environment and to determine which mitigating measures are most effective.

EcoVision received a number of publications with relevant information.

10 Monitoring

10.1 Monitoring of water quality and impacted corals

The Association for Waterborne Transport Infrastructure (PIANC) prepared an extensive document on best practices for dredging near coral reefs (PIANC, 2010), including a chapter on monitoring. The following monitoring strategy is derived from this document.

Monitoring and adaptive management

Monitoring is required to confirm that a project is meeting the agreed level of impact. Inclusion of an adaptive management process allows for maximum productivity of construction and dredging while still meeting environmental protection criteria.

EMP

For dredging, it is best practice to produce an Environmental Management Plan (EMP) by a specialized consultant, as part of the tender specifications for the Contractor. After award of the contracts, the EMP should be updated with the Contractor's detailed methodology.
Mitigation measures (e.g. environmental windows, spill budget, equipment, silt screens, etc.) should be explicitly incorporated into the contractor's operational documents.

EMP Baseline

An EMP baseline, covering the principal environmental receptors (e.g. coral reefs) and existing conditions (e.g. water quality, natural sedimentation rates, current velocities) is required to provide a measure of the pre-project conditions at impact and control sites. This is especially important for water quality parameters, since these have not been established in Saba so far.
Monitoring of waves is done since 2020 and is currently ongoing. A 2.5-month period of currents and turbidity monitoring is performed in end 2021. This monitoring shall be expanded and the measured turbidity values (FTU) shall be validated with actual water/sediment samples from site, to establish a reliable and site-specific correlation between FTU and TSS. This data may be used to set more refined TSS threshold limits during the execution.

Monitoring should be performed in conjunction with older data as well in order to establish the seasonal and statistical variability in the natural conditions.
EMP baseline survey components should address light attenuation and/or turbidity, sedimentation, coral health, currents, waves, morphology, water quality and associated ecosystems (e.g. nearby seagrass bed).
The number and location of monitoring sites should consider the predicted impact area (impact and control sites) and habitat variability.

Proactive feedback management

It is best practice to adopt a proactive feedback management. This is an approach in which specific (tiered) responses are agreed upon, on exceedance of certain parameters monitored. In this method, tolerance limits are used to identify potential impacts before they occur. Results from online instrumentation (at coral reef receptors, such as turbidity, suspended solids concentrations, sedimentation) are used as indirect indicators of potential coral health impacts based upon tolerance limits, which are updated as coral health monitoring data are collected as the works progress (the so-called feedback loop).

The primary control to comply with tolerance limits is through spill budget control, i.e. the maximum amount of sediment spill that can be released into the environment while still ensuring that the environmental objectives (in terms of coral health) will be met.
Predictive numerical modeling is applied to hindcast the location of the plumes from the construction operations. These modeling results are compared with biological monitoring (coral health) in order to check if adaptation of the methods is needed. They also help to better predict impacts between monitoring stations.

Tiered responses can be:

- reducing production (e.g. under low currents);
- restricting production (e.g. no production during reversed currents);
- changing the work method (e.g. equipment change, addition of silt screens, schedule change).

Post-project monitoring

Post-project monitoring is critical to ensure that predictions made at the EIA stage were accurate, and that the EMP was effective. It also allows for continuous improvement for future projects.

10.2 Monitoring success of coral relocation project

The success of the coral relocation project for colonies of protected species from the footprint area and high-risk zone to other high quality areas can be measured in a variety of different ways. The indicators used to measure the success of this project are based on the project goals. These goals could be: coral population enhancement, increase in genetic diversity, socio-economic involvement and eco-tourism engagement.
For coral population enhancement goals, factors such as change of ecological footprint from total outplanted area, coral cover %, live tissue %, reproductive capacity are examples of metrics that can be useful.
In a first stage, a monitoring protocol with clear achievable metrics will be drafted and be decided upon. This protocol will then be executed. It is recommended to execute a long term (5 years) monitoring program and to compare the transplanted corals to non-transplanted coral colonies at the same time, to determine solid conclusions about the success of the project.

10.3 Monitoring of colony of red-billed tropicbird

Before, during and after the main construction works an ornithologist (bird expert) will monitor the behavior of the red-billed tropic birds for signs of stress. As a first step, a monitoring plan will be drafted by the anticipated expert.
The behavior of both adult birds and chicks will be monitored, since they have very different behavior patterns. Adult birds fly to open sea during the morning and return back to their nests at approximately 16.00 p.m. Chicks will stay on their nests and may suffer more stress.
The monitoring during the construction works may lead to the decision to change working methods, such as adaptation of working hours.

10.4 Monitoring of marine mammals

If the cofferdam structure is chosen as the most suitable alternative, observation of marine mammals will take place in a zone with a 5 km radius, during working hours. If mammals are observed within a smaller zone (2 km radius), measures will be taken in order to prevent damage to the animals (see paragraph 7.2).

10.5 Monitoring of erosion in watershed areas

Since erosion in the three watershed areas near the proposed and current harbor, of which 1 is linked to the harbor project, is taking disastrous proportions. It is essential to monitor this phenomenon, both in the current situation, during construction and in the years after construction.

11 Conclusions and recommendations

11.1 Conclusions

Main conclusion

The EIA demonstrates that a number of impacts can be reduced to the level "moderate" or lower. A number of impacts however remain at the level "significant". The most important ones are:

- loss of ecological values in the terrestrial footprint, such as removal and disturbance of habitat for terrestrial species of high conservation value and habitat fragmentation;
- loss of ecological values in the marine footprint, mainly removal and disturbance of habitat for protected corals and other marine species of conservation value;
- anticipated loss of 35% of the 246 transplanted colonies of protected species (amounting to 80-90 colonies)
- disturbance of a colony of red-billed tropicbird at St. John's Cliffs (80-100 nests) during construction of the gabion weirs
- impacts on landscape, the catalyzation of other future developments
- erosion in the project area and sedimentation of nearby patch reefs
- in case of the choice for a cofferdam breakwater, possible harm to marine organisms (including sea mammals) due to noise.

Comparable impacts from the alternative project, renovation of the Fort Bay harbor, are considerably less in intensity and duration (EcoVision, 2019, see next summary).

Preferred technology

From an ecological point of view, a caisson structure for the breakwater is the preferred option, because (1) it results in a smaller footprint than the base case, (2) it results in the relocation of less protected corals compared to the base case and (3) it results in significantly less noise for the colony of red-billed tropic bird (approximately 200 birds / 100 nests at St. Johns Cliffs) and for marine fauna, including sea mammals.

The cofferdam construction-method will create more noise (underwater and above water) because of a period of 4 months of intensive pile driving. If this method is preferred from a viewpoint of harbor construction, a quantitative noise assessment is needed (both terrestrial and marine), to demonstrate that disturbance will remain at acceptable levels.

Erosion and sedimentation

Erosion in the three watershed areas near the proposed and current harbor is taking extreme proportions, and is harming the marine environment in the waters south of Saba. This is already the case in the current situation. The proposed construction of a new harbor will certainly contribute to this. Therefore, impact mitigation is crucial. Slope stabilization and revegetation could have a longer-term positive impact.
Although more research is needed into background turbidity, sedimentation and current velocities in the waters of south Saba, impacts from elevated turbidity and sedimentation by marine construction and dredging are considered to be less impactful than sedimentation by terrestrial construction, which takes place on a wider scale and during a longer period.

Stakeholders views

Of five stakeholders contacted, one is opposed to the harbour project (dive operators), two have certain concerns but are not directly opposed (Saba Conservation Foundation and [redacted]) and two are in favour (fishermen, Government). Most stakeholders agree on adequate compensation for ecological impact.

11.2 Recommendations

Immediate and full execution of all proposed mitigating measures

In case of a positive decision in favor of the harbor development at Black Rocks, it is strongly recommended to immediately and fully execute all proposed mitigating measures. Especially slope stabilization and revegetation alongside the roads should start immediately after profiling of the slopes, well before road paving takes place, to reduce erosion and sedimentation. Likewise, slope stabilization and revegetation at the weirs and temporal revegetation of the harbor area should take place immediately after construction and levelling.

Uncontrolled development in the Black Rocks harbor area should be prevented to the maximum by the Saba Government.

Preferred technology for construction of breakwater

From an ecological and environmental point of view, it is recommended to construct the breakwater as a caisson structure. If the choice is made for a cofferdam structure, it is recommended to select the method of vibro-driving for the piles and to carry out a quantitative acoustic assessment (both terrestrial and marine), based on this choice. Based on this study finetuning of mitigating measures can take place (e.g. defining safety zones for marine mammals).

If the choice is made for a berm breakwater, it is recommended to use a caisson structure at the quay side of the breakwater. This will result in the use of 35% less backfill material and will considerably lower turbidity and sedimentation.

Research

In addition to the research that has already taken place (see Annex 14), it is recommended to carry out further research into background turbidity, light attenuation, sedimentation and current velocities in the waters near Black Rocks for at least 3 months. These data can help refine the chosen (preliminary) thresholds for background turbidity and sedimentation for marine construction and dredging. The marine works should comply with the final thresholds.

Compensation campaign

In case of a positive decision from the OLS in favor of the harbor development at Black Rocks, it is strongly recommended to start an extensive campaign with the purpose of compensating for ecological losses and impacts.

One option for compensation may be the island wide definition of a coastal zone where only limited development and low impact development should be allowed and where erosion control measures will be carried out (e.g. through the Saba Marine Environment Ordinance).

Another option for compensation is the complete ecological restoration and revegetation of the three heavily disturbed watershed areas in the South of Saba: the lower parts of the watershed area of Fort Bay (near the access road) and the two watershed areas west and east of Sint John's (higher and lower parts, including the stone mine). Provided that goats will be kept out of the area, reforestation and revegetation of these areas will restore the natural runoff patterns, and reduce sedimentation of Saba's south coast reefs (including Tent), which will be an important step towards to restoring these coral reefs on the longer term.

Other possible compensation measures with positive impacts are:

- Relocation of all corals and sponges, not only protected corals
- Creation of artificial reefs, in line with "Diadema City" (see chapter 9) at Gary's Pond, which provides shelter for at least 2000 specimens of Diadema antillarum, a large quantity of fish with high fish diversity, and very good conditions for coral recruitment
- Create a fund for coral restoration projects
- Compensation of the loss of 2 dive sites by creating a spot for divers and snorkelers near the harbor, where they can work on coral (restoration or monitoring) projects;
- Adequate management of waste water all over the island
- Enforcement of BES Bouwbesluit (building regulations)

Monitoring

It is recommended that the Harbor Project Organization and The Public Entity of Saba draft and execute or order for monitoring plans for the following situations:

- Baseline survey on water quality (turbidity, light attenuation, sedimentation), currents, waves, coral reef health, and associated ecosystems during 3 months (part of Environmental Management Plan by specialized consultant/Contractor);
- Monitoring of corals impacted by construction activities (part of Environmental Management Plan by specialized consultant/Contractor);
- Monitoring of relocated corals;
- Monitoring of colony of red-billed tropicbird at St. Johns' Cliffs;
- Monitoring of quantity and quality of runoff in the new harbor area before, during and after construction;
- Monitoring of sea mammals during pile driving during 4 months (in case of cofferdam breakwater).

Monitoring results will be used for final definition of thresholds for suspended solids and sedimentation and for adaptive management (changing works when needed).

Timely submission of request for exemption at the Scientific and Technical Advisory Committee (STAC) of the SPAW Protocol

For the relocation of approximately 246 protected colonies an exemption needs to be submitted to the Scientific and Technical Advisory Committee (STAC). As STAC meetings are held infrequently, it is recommended to submit a request for exemption as soon as possible (ultimately 3 months in advance of a planned meeting).
Before submission it is recommended to:

- prepare a draft decision by the Minister of Agriculture, Nature and Food Quality, based on article 13 (paragraph 1 and 2) and article 8b of the Law on nature management BES;
- finalize the results of the pilot project for selecting the best location for relocation;
- Assess numbers of *Acropora palmata* in other sites of Saba. SFC is currently working on this.

Other recommendations

The resolutions of the Dutch Parliament with respect to impacts in coral reefs in Bonaire may present a risk for the Black Rocks project. It is recommended to further evaluate their significance and implications.

The Saba Conservation Foundation (SCF) may define additional recommendations and conditions that need to be met before, during and after the construction activities.

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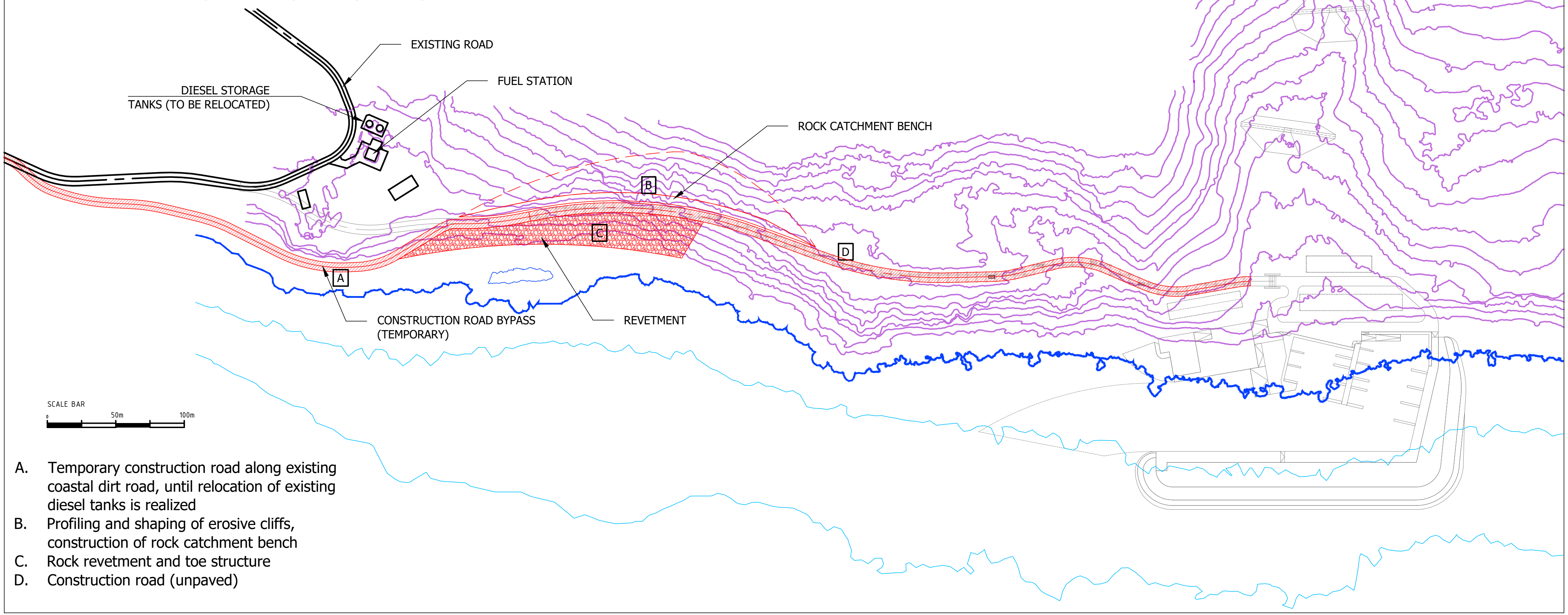
Annexes

Annex 1: Construction phasing

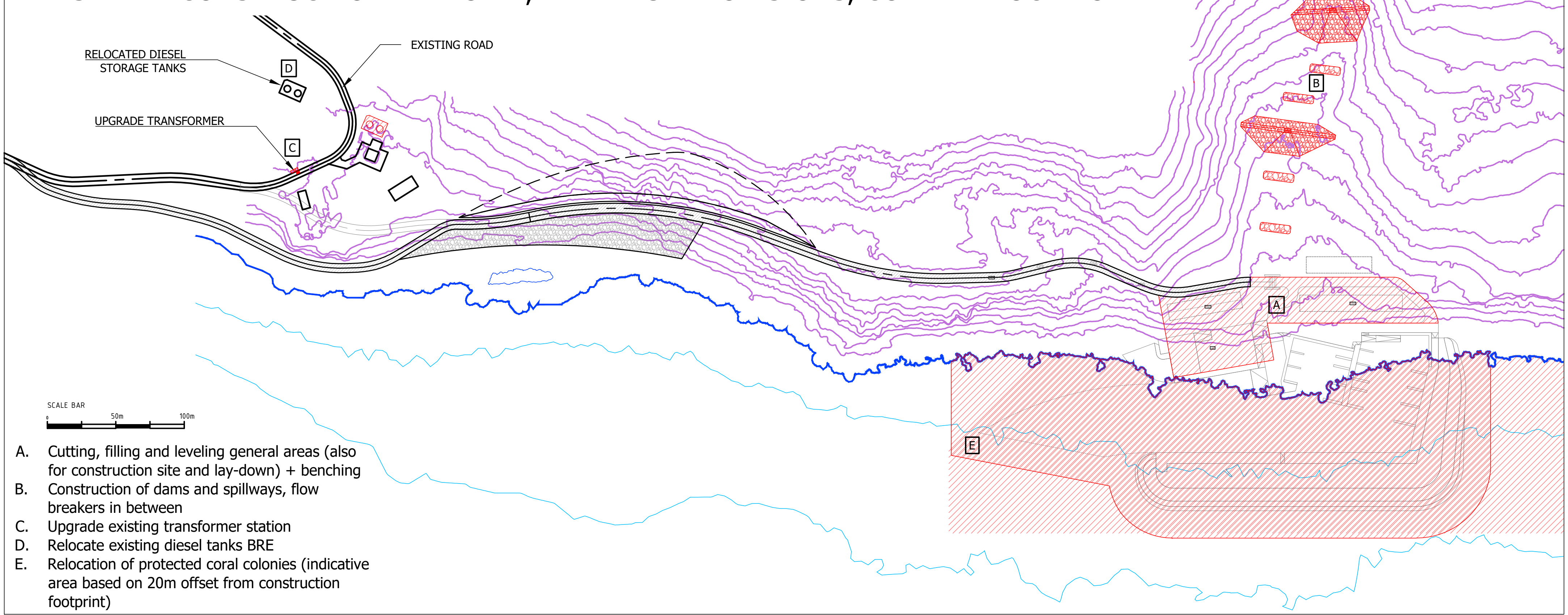
PHASE 1 - ENABLING WORKS

PHASE 1.1 - CONSTRUCTION ROAD



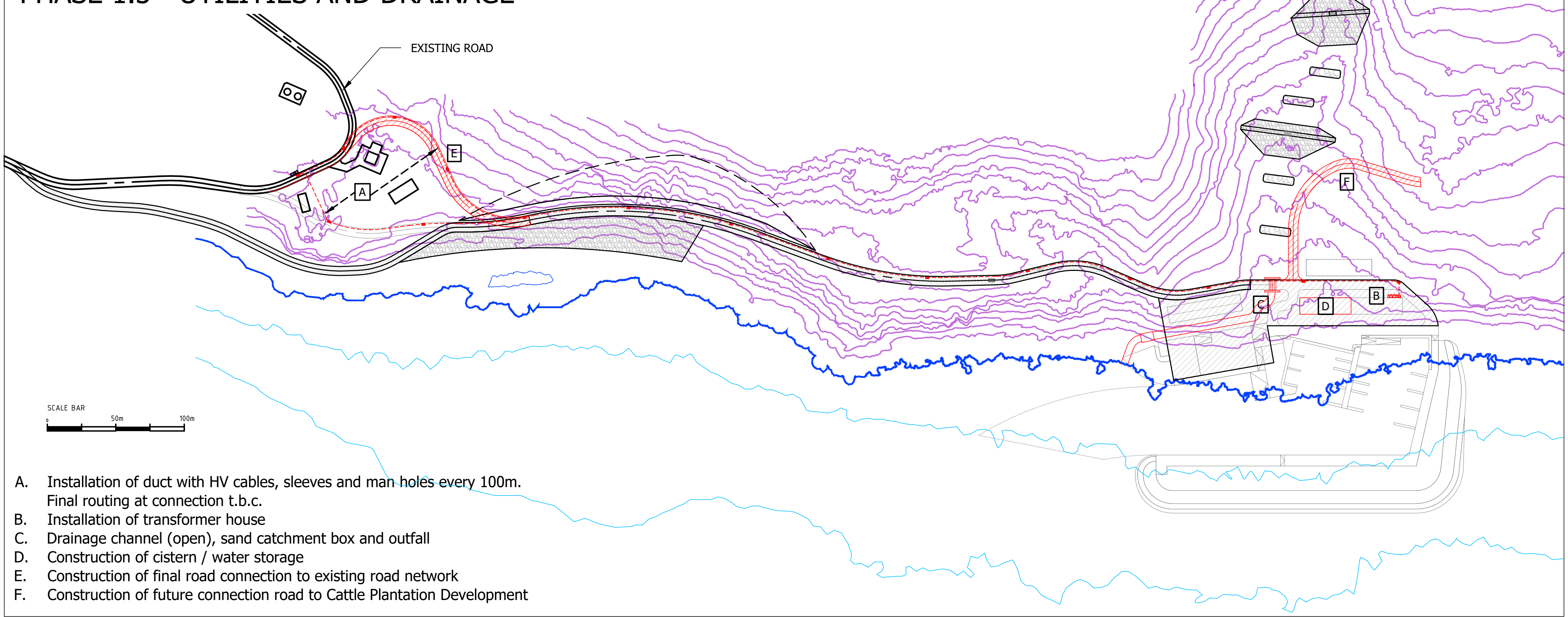
A. Temporary construction road along existing coastal dirt road, until relocation of existing diesel tanks is realized
B. Profiling and shaping of erosive cliffs, construction of rock catchment bench
C. Rock revetment and toe structure
D. Construction road (unpaved)

PHASE 1.2 - CONSTRUCTION LAYDOWN, DRAINAGE PROVISIONS, CORAL RELOCATION



A. Cutting, filling and leveling general areas (also for construction site and lay-down) + benching
B. Construction of dams and spillways, flow breakers in between
C. Upgrade existing transformer station
D. Relocate existing diesel tanks BRE
E. Relocation of protected coral colonies (indicative area based on 20m offset from construction footprint)

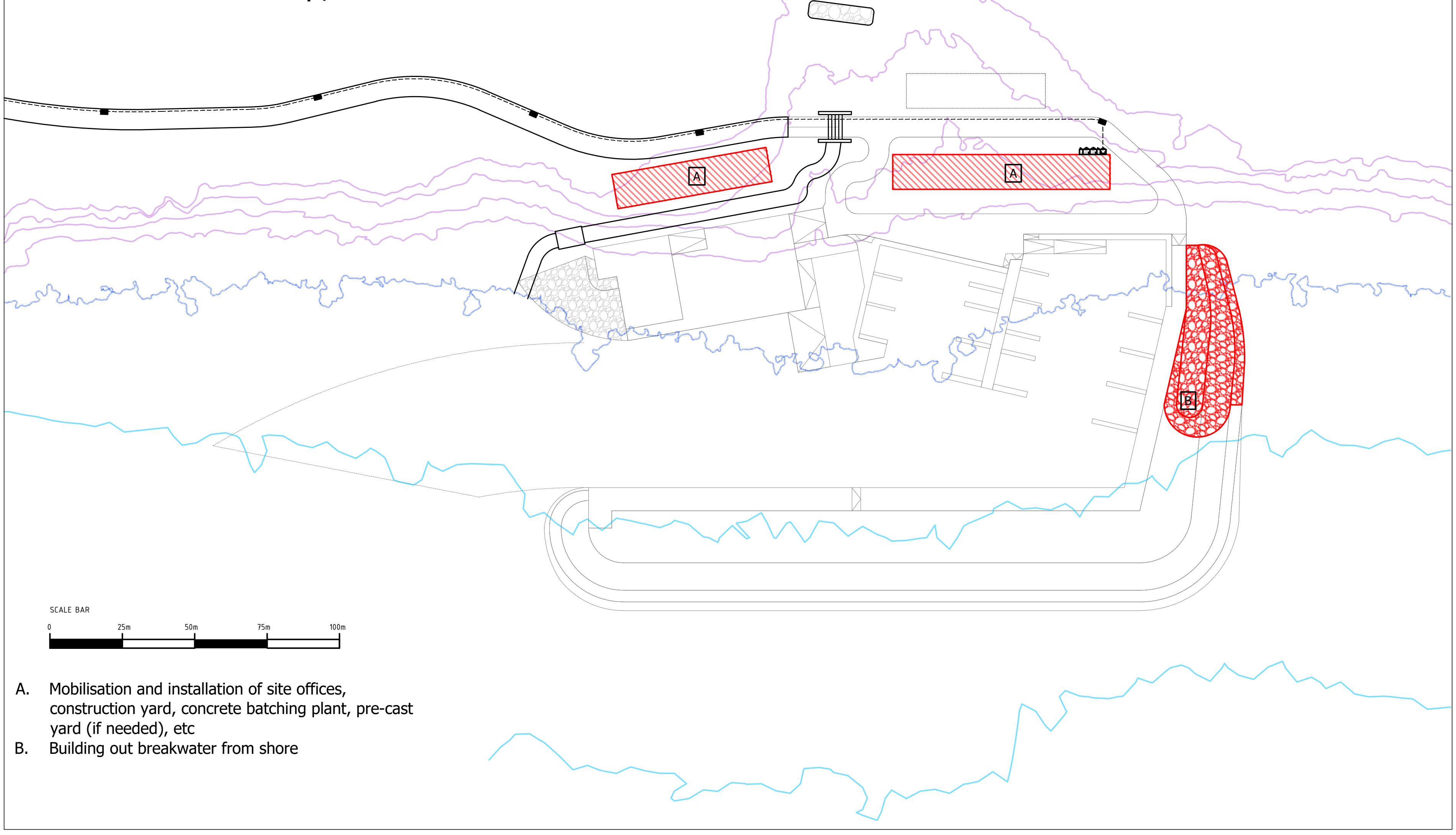
PHASE 1.3 - UTILITIES AND DRAINAGE



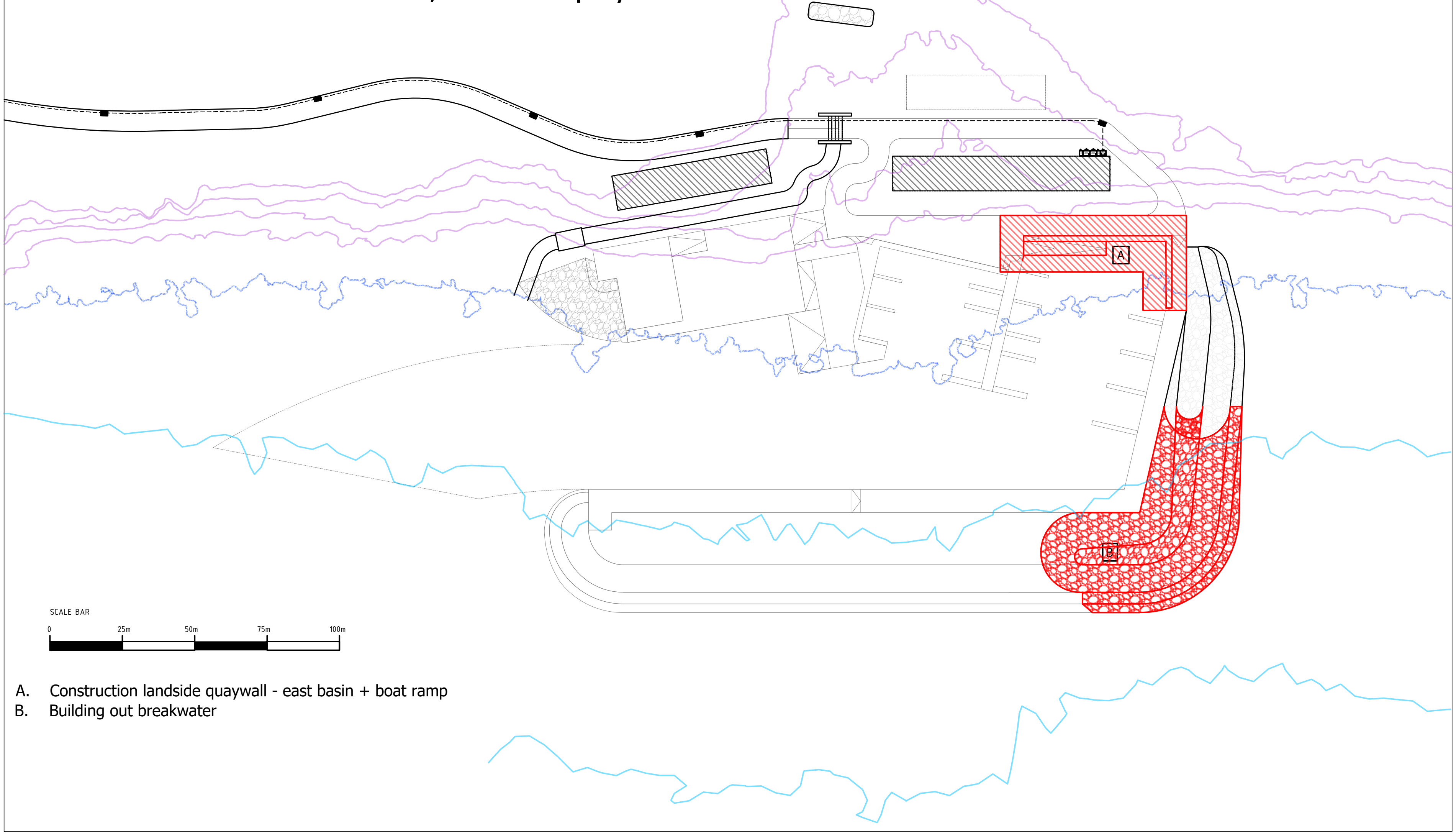
A. Installation of duct with HV cables, sleeves and man holes every 100m. Final routing at connection t.b.c.
B. Installation of transformer house
C. Drainage channel (open), sand catchment box and outfall
D. Construction of cistern / water storage
E. Construction of final road connection to existing road network
F. Construction of future connection road to Cattle Plantation Development

PHASE 2 - MARINE CONSTRUCTION WORKS

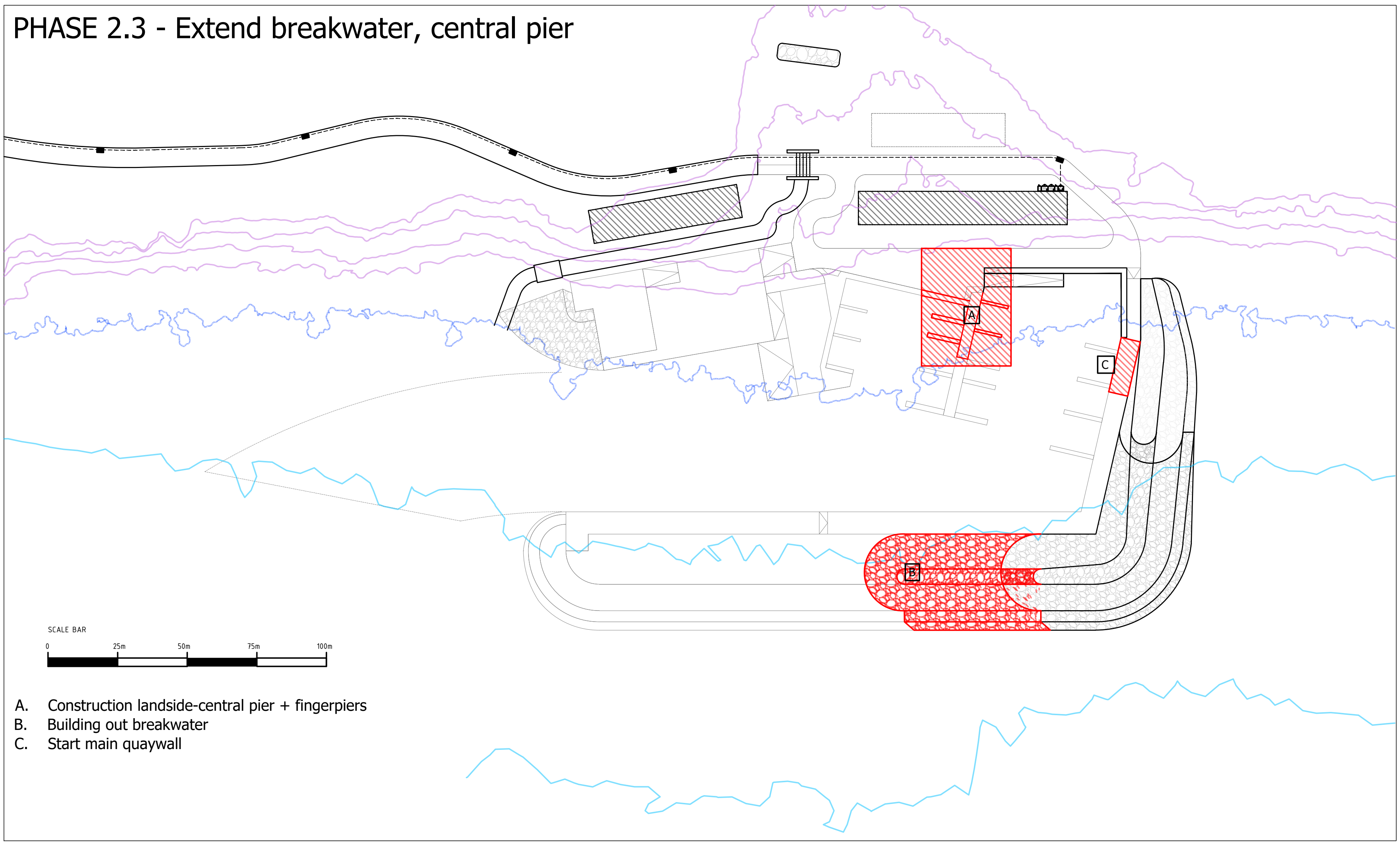
PHASE 2.1 - Site set up, start breakwater



PHASE 2.2 - Extend breakwater, landside quay wall east

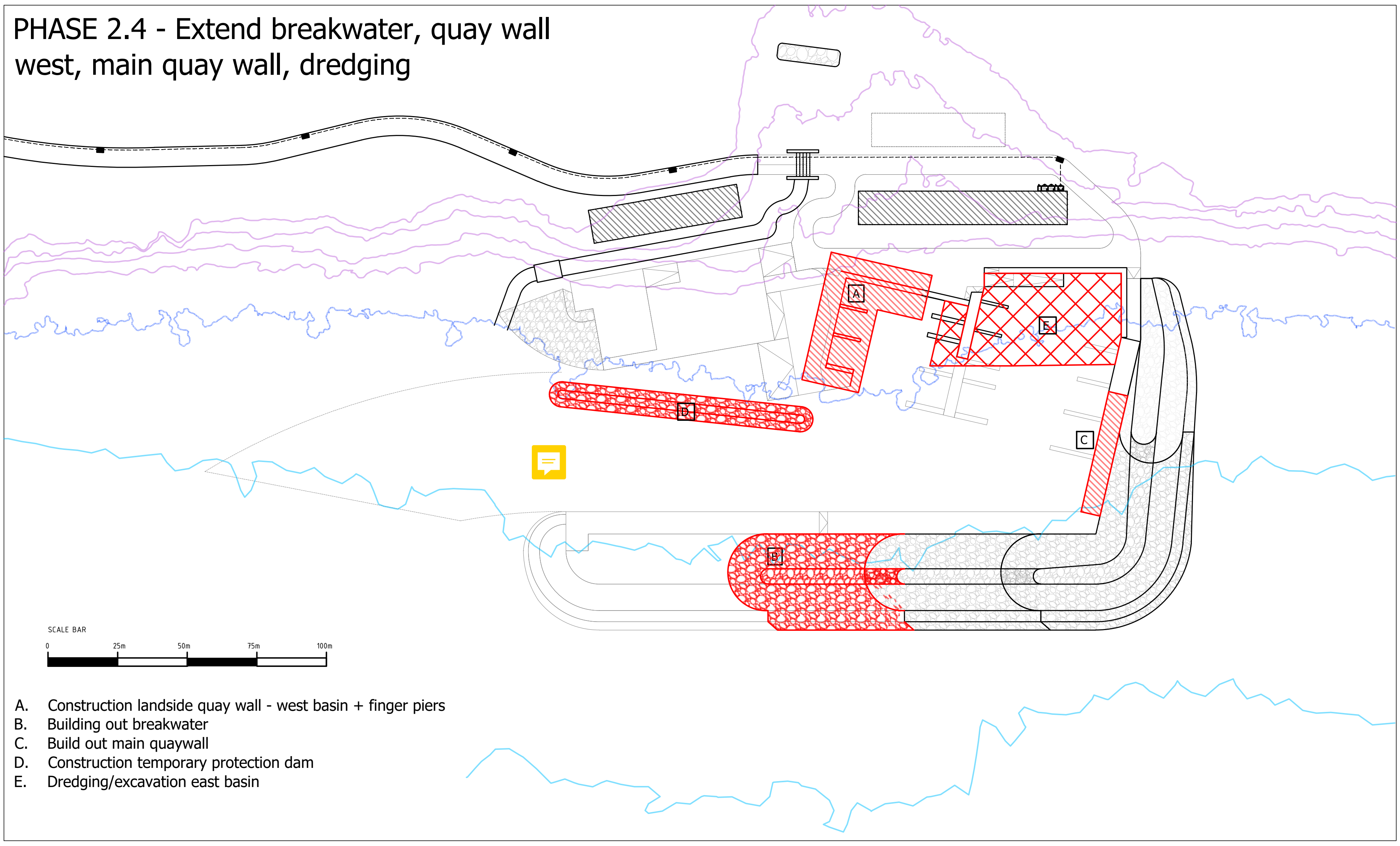


PHASE 2.3 - Extend breakwater, central pier



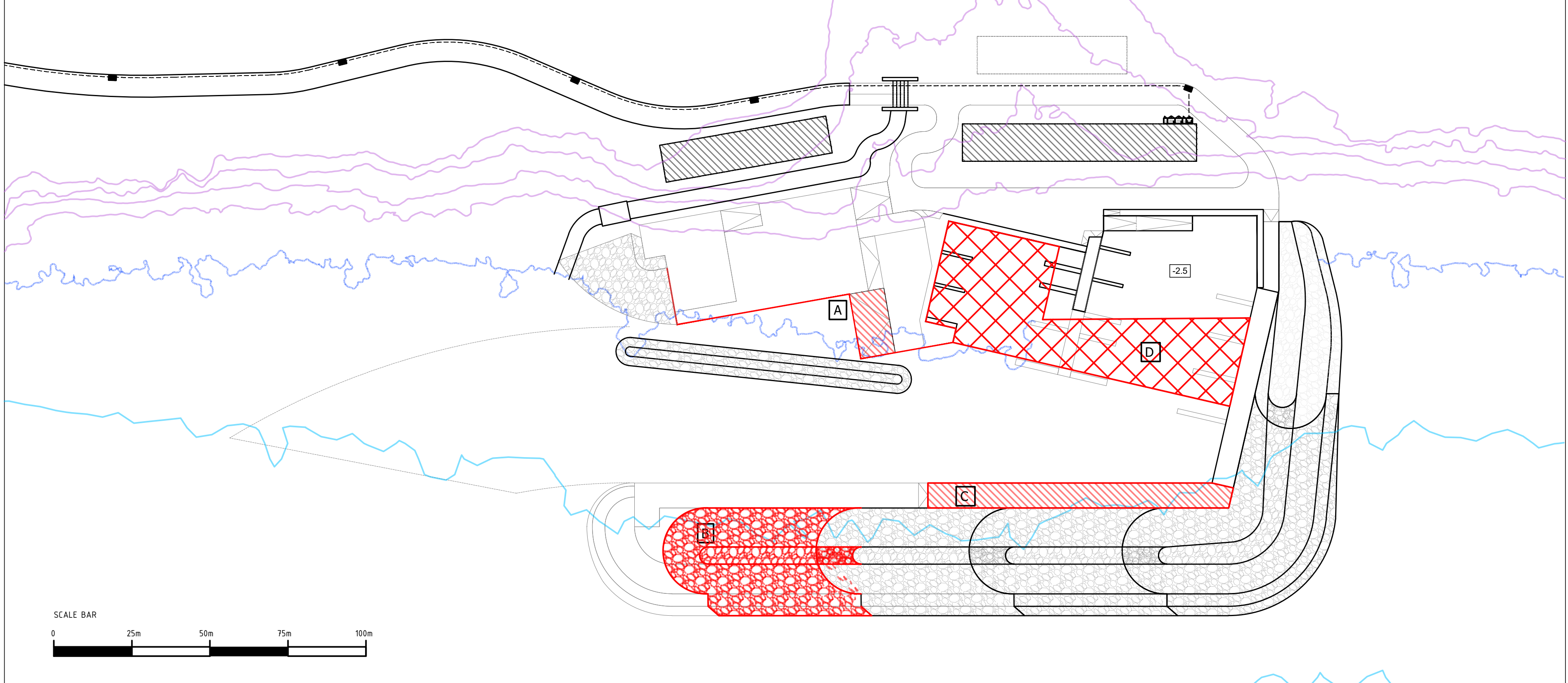
A. Construction landside-central pier + fingerpiers
B. Building out breakwater
C. Start main quaywall

PHASE 2.4 - Extend breakwater, quay wall west, main quay wall, dredging



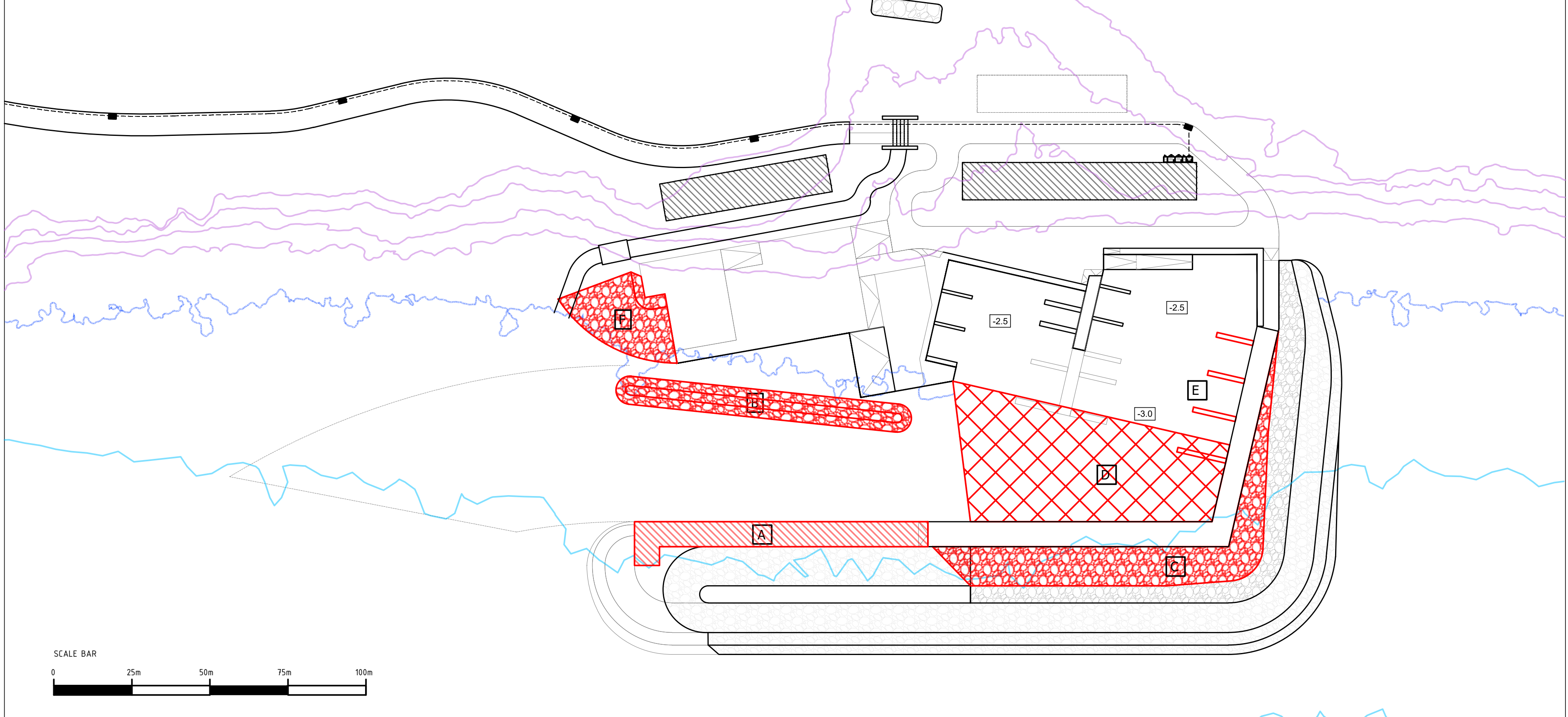
A. Construction landside quay wall - west basin + finger piers
B. Building out breakwater
C. Build out main quaywall
D. Construction temporary protection dam
E. Dredging/excavation east basin

PHASE 2.5 - Extend breakwater, main quay wall, RoRo pier, dredging



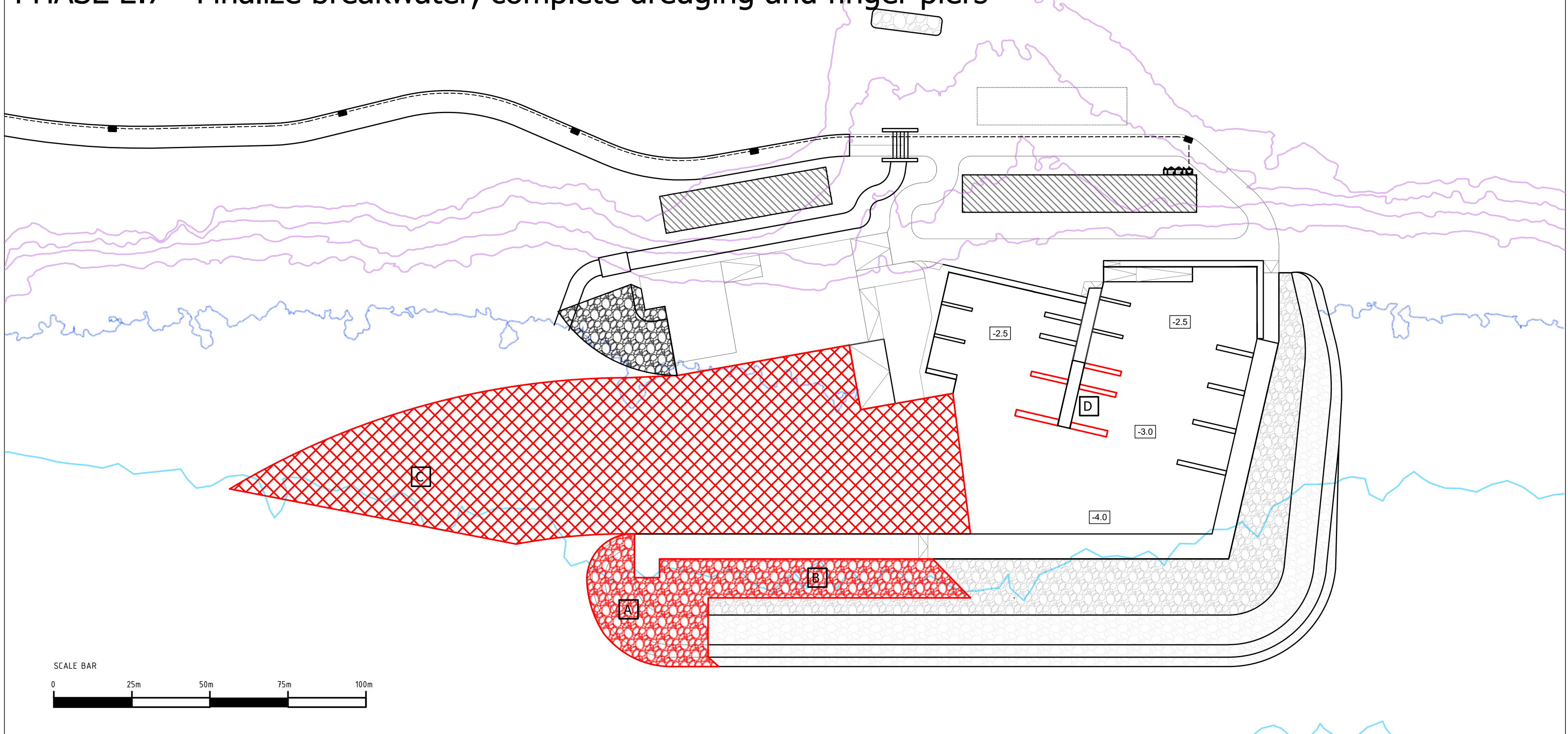
A. Construction landside quay wall - west basin + finger piers
B. Building out breakwater
C. Build out main quaywall
D. Dredging / excavation east&west basin

PHASE 2.6 - Breakwater head, dredging



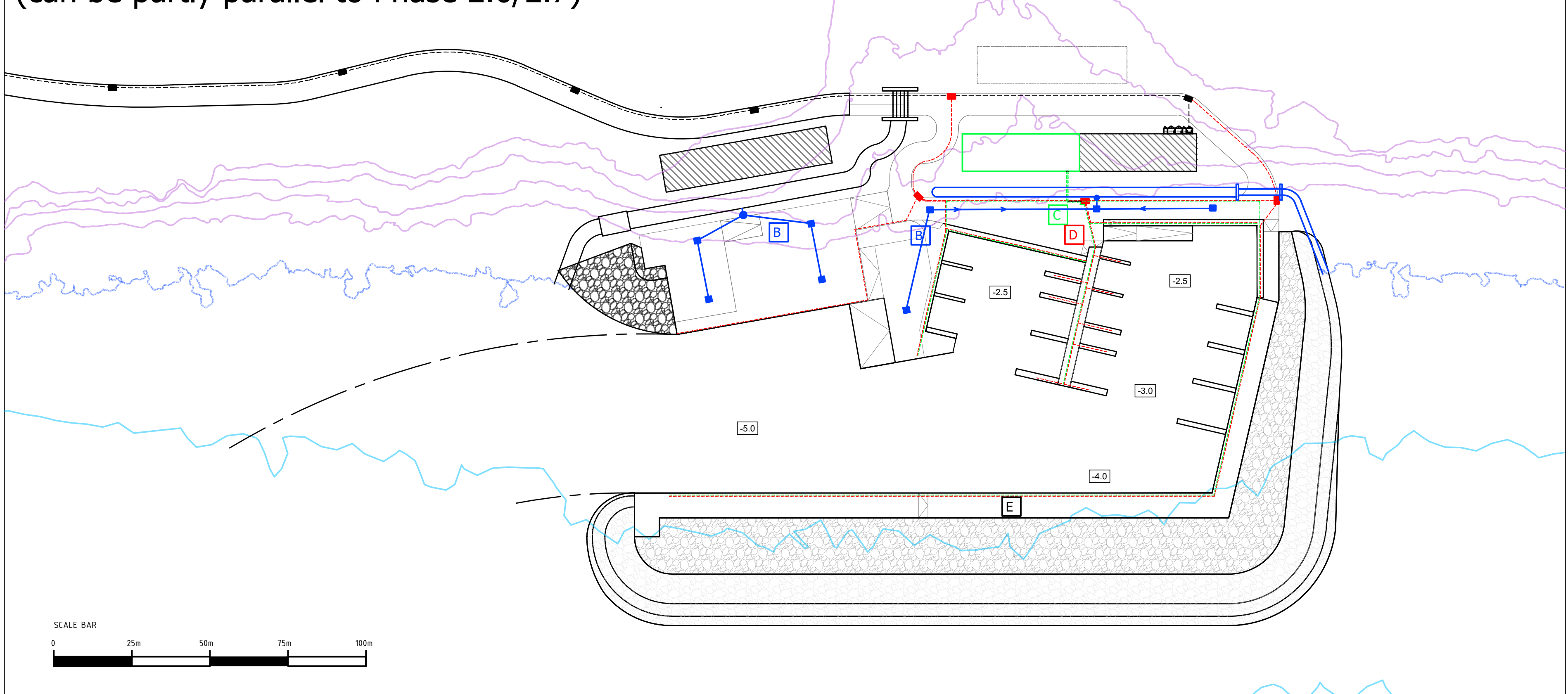
A. Build out main quay wall + breakwater head
B. Remove temporary dam
C. Back-fill main quay wall / breakwater
D. Dredging main quay wall east
E. Construction finger piers east
F. Install revetment RoRo quay

PHASE 2.7 - Finalize breakwater, complete dredging and finger piers



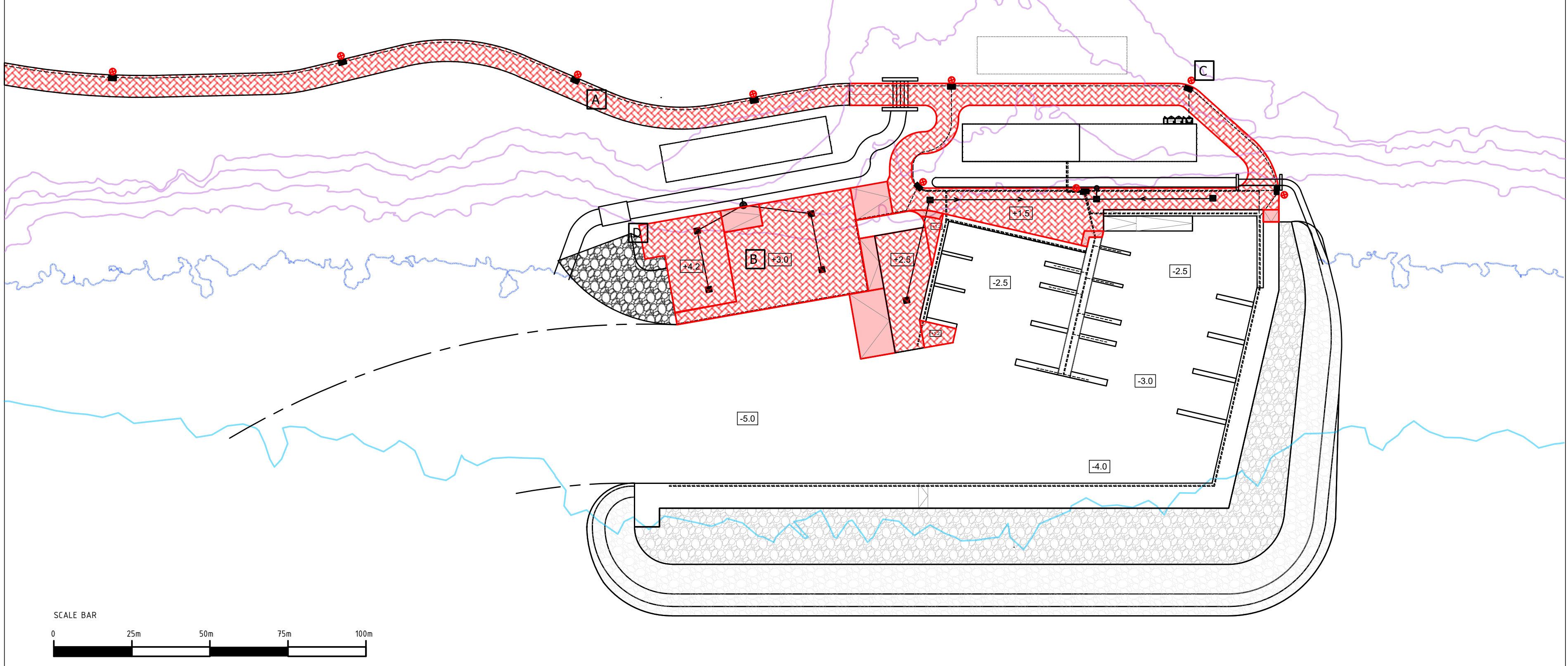
A. Build out main quay wall + breakwater head
B. Back-fill main quay wall / breakwater
C. Dredging RoRo quay and main channel
D. Construction central pier/finger piers

PHASE 2.8 - Utilities
(can be partly parallel to Phase 2.6/2.7)



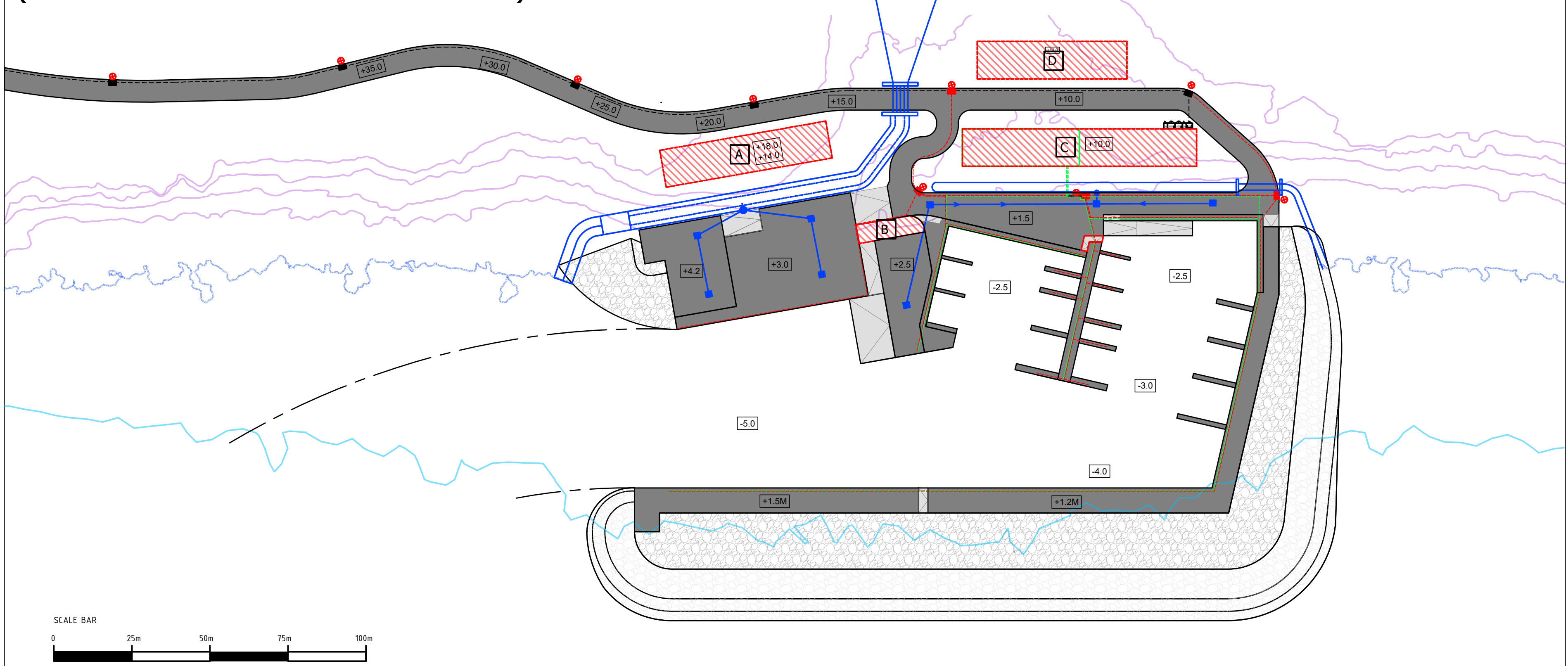
A. Bollards, fenders and navigation lighting
B. Drainage system with soil separators and sand catchment
C. Water piping from cistern
D. Electricity
E. Connection boxes / pedestals

PHASE 2.9 Pavement and lighting
(can be partly parallel to Phase 2.7/2.8)



A. Final pavement of road, incl rock retaining walls where needed
B. Harbour area pavement
C. General lighting
D. Fencing

PHASE 2.10 COMPLETION
(BUILDINGS IN OTHER CONTRACT)



A. Fishermen's building / warehouse
B. Customs/Immigration
C. Harbour Master / SCF / Lounge / Restaurant
D. Tour operators / others

Annex 2: Ecological surveys

2a: Report of terrestrial ecological survey, Saba Conservation Foundation

Island **Saba**

Project **Black Rock / Giles Quarter Harbour Project**

Report **Ecological survey of vegetation, birds and fauna**

Location **TERRESTRIAL AREA NORTH OF PROPOSED SITE**

Date **May 2021**

Date: May 2021
Title Terrestrial Surveys: Black Rocks/Giles Quarter Harbour Projects Report
Authors: [redacted]
Organisations: Parks – Work : [redacted]
Saba Conservation Foundation: [redacted]

About this document
This Technical Report has been prepared by [redacted] in response to a Terms of Reference drafted by EcoVision (appointed environmental consultant for the Black Rocks Harbour project) and issued by [redacted], representative of the Public Entity of Saba for the Harbour Project, regarding the projected development of a new harbour at Giles Quarter on Saba. The scope of work included conducting field surveys and providing a short technical report on the terrestrial vegetation, birds and fauna of an area north of the projected development.

This work package was initiated in September 2020 with field work carried out during the final quarter of 2020 and first quarter 2021. This report has been prepared to conform with the specifications provided in the Scope of Work document dated 12th November 2020 using the survey results and literature survey.

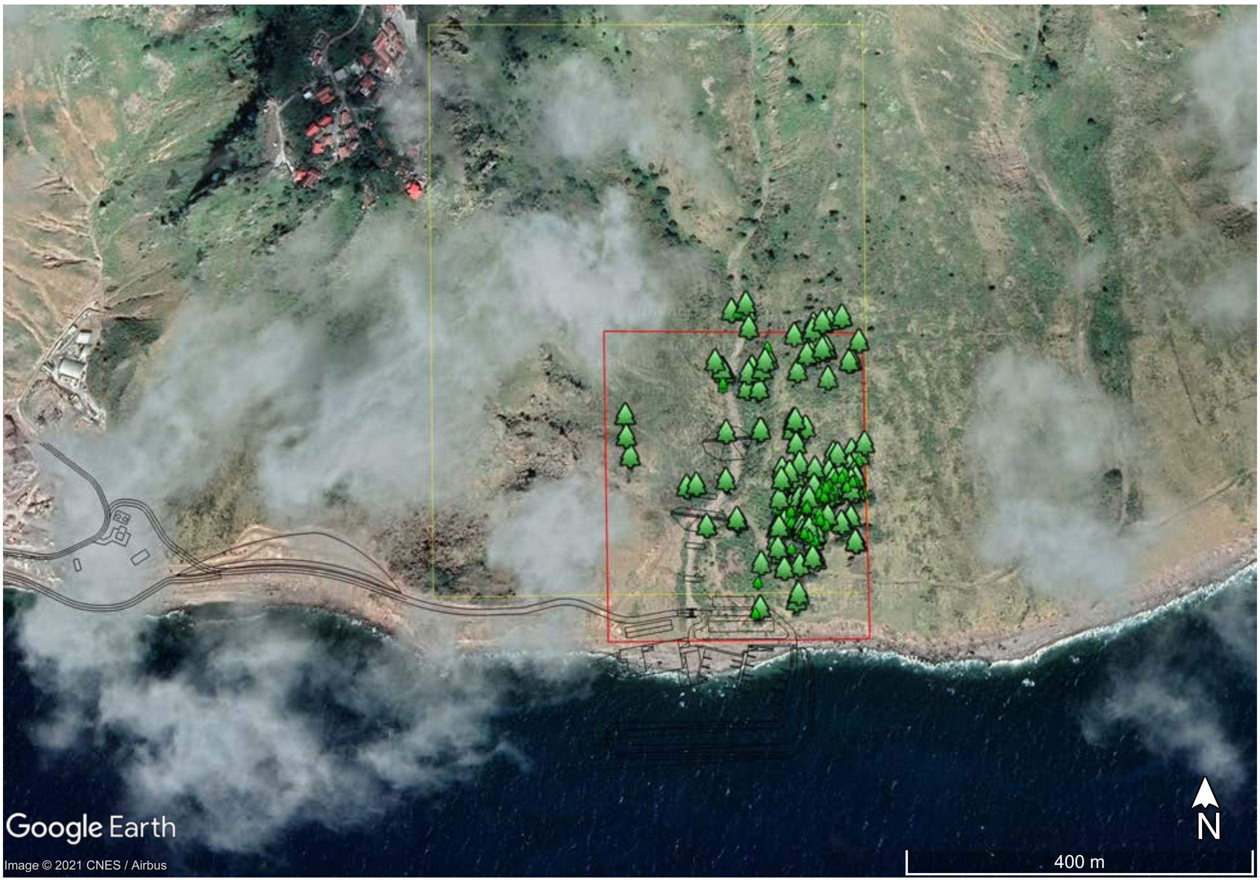
Acknowledgements
Content for this Technical Report came from a number of sources including, field work carried out by Saba Conservation staff, literature survey and expert consultation.

Citation
MacRae, D.R., De Meyer K., and Wulf, K. Terrestrial Surveys: Black Rocks/Giles Quarter Harbour Projects Report

Summary

Following plans to redevelop the harbour at Fort Bay, a site for a new harbour complex was identified at Giles Quarter and proposed in 2019/2020. This report provides the results of a literature study and terrestrial survey work, carried out by staff of the Saba Conservation Foundation within the proposed development area. Brief field surveys focused on the vegetation and bird species present in the vicinity of the proposed development area. Vegetation was surveyed and fauna noted throughout the area shown in red on the map below (Figure 1) where the presence of trees 30cm – 50 cm stem circumference (dbh) as well as trees with a stem circumference over 50cm was recorded with GPS co-ordinates. The presence of birds was recorded within the yellow area in Figure 1.

Figure 1 Harbour and survey site



Legend: Large Green trees = dbh >50cm, small trees = dbh 30cm-50cm,
Red line= tree survey area, yellow line = bird survey area

Vegetation

- The dominant species in the area are Manchineel (*Hippomane mancinella) which form notable forests within the survey site*. This is an unusual vegetation type for Saba
- There are 14 trees with DBH >50m and two more with DBH 30cm-50cm within the location of the dam construction sites and close upstream
- In total 32 rare species were identified by Saba Conservation Foundation based on The Landscape Ecological Vegetation Map of Saba [De Freitas et.al. (2016)]
- The Cana gorda girdlepod (*Mitracarpus polyclades*) can be found within the survey site. This is an endangered species which is known to be endemic to Puerto Rico and Saba.
- The Bastard tobacco (*Cordia nesophila*) is another tree with a restricted range found within the study site

Birds

Red-billed tropicbirds (*Phaethon aethereus*) are present and have been observed nesting within the survey area

- Red-billed tropicbird conservation is addressed in the Nature & Environment Policy Plan Caribbean Netherlands 2020 -2030 (unpublished)

- The entire coastline of Saba is considered an Important Bird Area (AN006) and Saba is particularly noted for its breeding seabird populations, particularly Red-billed tropicbirds
- An estimated 2,250-3.000 Red-billed tropicbirds congregate on Saba. The global population is estimated at 30,000 birds and Saba's Red-billed tropicbird population is therefore considered globally significant
- An estimated 750-1000 pairs of Red-billed tropicbirds nest on Saba. 100 pairs are believed to nest within the study area
- Red-billed tropicbirds are a flagship species for Saba

Audubon's shearwater (*Puffinus lherminieri*) have been found nesting within and near the survey area;

- Audubon's shearwater are included on the SPAW II annex of species
- Audubon's shearwater conservation is addressed in the Nature & Environment Policy Plan Caribbean Netherlands 2020 -2030 (unpublished)
- The entire coastline of Saba is considered an Important Bird Area (AN006) and Saba is particularly noted for its breeding seabird populations, particularly Audubons shearwater
- The nesting population is believed to be around 1,000 birrds
- Audubon's shearwater are the National Bird of Saba and are considered a Flagship species

Zenadia doves (*Zenadia aurita*) were observed in the survey area

- Zenadia doves are a restricted range species

Other fauna
Other fauna of conservation importance include three iguana species, four lizards and one snake all of which are believed to be found at the site:

- The Lesser Antillean Iguana (*Iguana delicatissima) an IUCN Red List Critically endangered species is believed to be present within the study site.*
- The Melanistic Lesser Antilles Iguana (*Iguana melanoderma) is believed to be present in the study site is thought to be endemic*
- The Red bellied racer snake (*Alsophis rufiventris) has a restricted range and is an IUCN Red List species considered Vulnerable to extinction.*

Issues for consideration

- The survey area has steep slopes, a deep gut running through the middle north to south and has very shallow topsoil over stony parent material making the area highly susceptible to sheet erosion and the harbour site vulnerable to sedimentation and boulder deposition.
- Development of the harbour will remove and disturb habitat for species of conservation importance as well as disturbing breeding and foraging behaviours through movement and noise pollution during development and throughout operations.
- Larger tree species and their network of roots are essential to bind the poorly consolidated soil
- Whilst the proposed dams and ponds will catch run off, hurricanes and other events associated with high rainfall will result in exceptional run off down the gut, combined with a storm surge, potentially inundating the proposed dams and posing critical problems for boats in the harbour.
- Due to global warming effects, storms, hurricanes and other extreme weather events are expected to increase in the coming years.
- The trees present in the gut exist there because they are very tolerant and well adapted to the current environmental conditions, changing those conditions is unlikely to favour them.
- Fragmented and degraded ecosystems will be less resilient and more likely to be damaged by the expected impacts of climates change such as increased storm events, precipitation and run off.
- The dam construction and associated activities should be designed to have the smallest possible footprint on the existing natural area and to cause the least disturbance to the flora and especially avifauna.
- The paving of the current dirt road between Fort Bay and the Habour site will require consolidation of the cliff face and slope which will help to stabilize this area and reduce sediment rich run off.
- A secondary road to the proposed harbour (Giles Quarter to Windwardside) will significantly impact vegetation, birds and other fauna on site and in the marine environment through habitat removal and increased erosion and run off.

Key references
Vegetation: Landscape ecological vegetation map of Saba (Lesser Antilles)
Birds: BirdLife International Data Zone

Contents

Tables

Boxes

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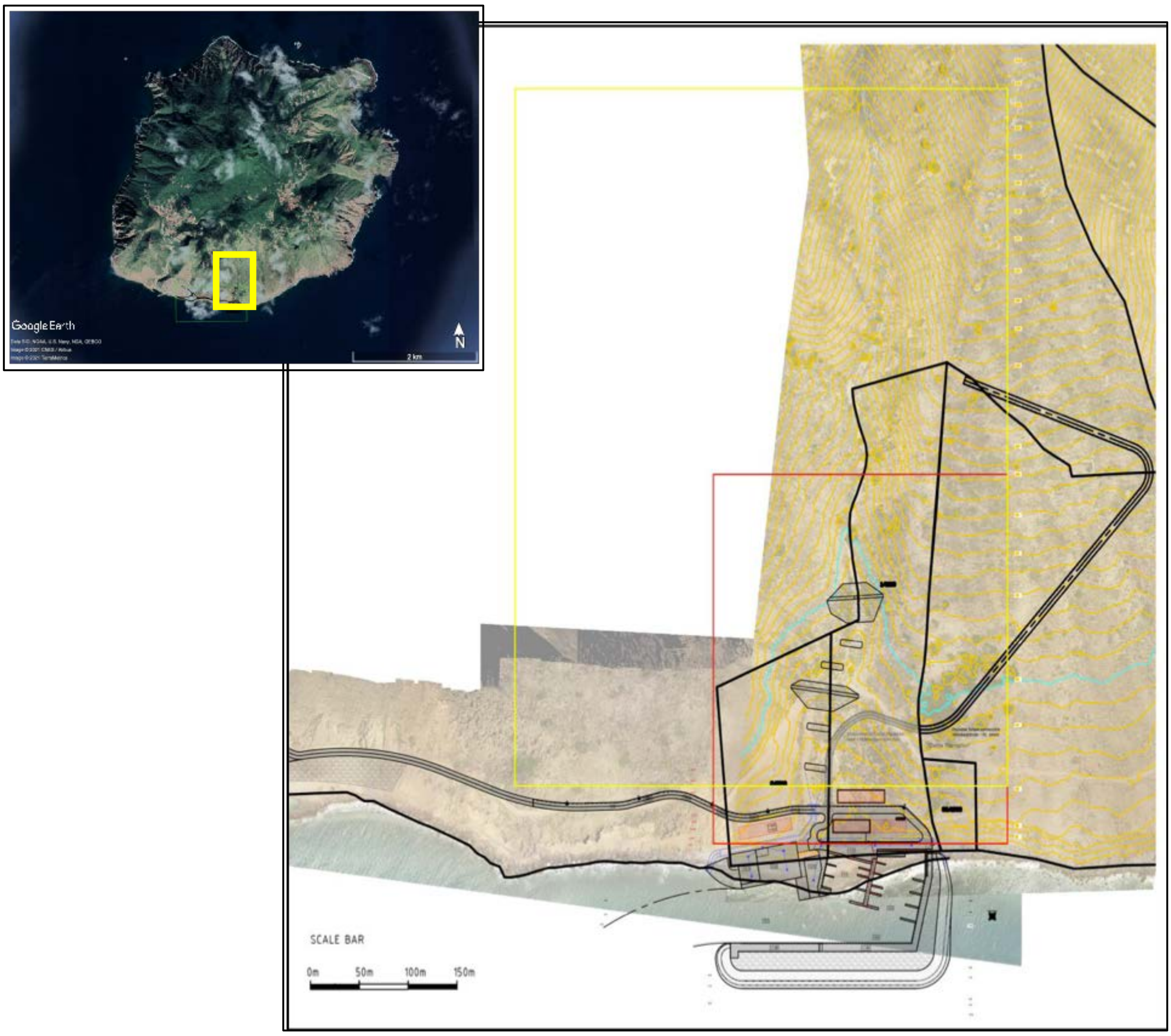
Project and location

Proposed development of a new harbour, ancillary roads and dams in Giles Quarter area of Saba, East of Fort Bay, South of St Johns. The proposed project and survey sites are located in the southern part of Saba, mostly to the south and east of the settlement at St Johns in the area known as Black Rocks / Giles Quarter (Figure 2).

Figure 2 Giles Quarter Harbour project location



The survey area has steep slopes, a deep gut running through the middle north to south, and has very shallow top soils over stony parent material making the area susceptible to sheet erosion. Rainfall on Saba varies from >2000mm per year on the summit to 760mm at the airport (Box 1). Lower slopes receive much of the runoff from upper slopes, particularly where vegetation cover is degraded.

Box 1 Climate extract from (de Freitas et al., 2016)

> The annual average rainfall on Saba as measured at the airport at about 30 m above sea level is 760.5 mm (1971-2000) . This is over 30% lower than the averages given for The Bottom which lies at altitudes of about 250 m (Stoffers (1956): 1133.5 mm (1947-1952); and Braak (1935): 1124 mm (1891-1898 & 1901-1933)). According to Veenobos (1955) precipitation is higher on the slopes of Mount Scenery and surpasses 2000 mm. This is e.g. reflected in more lush vegetation types above 500 m

Vegetation

Literature review

Landscape ecological vegetation map of Saba (Lesser Antilles)

(de Freitas et al., 2016) recorded the site as Aristida-Bothriochloa Mountains with at least 117 species represented across the assemblages (Box 2, map in Appendices).

Box 2 Extract on vegetation from (de Freitas et al., 2016) p38

> This Aristida - Bothriochloa landscape occurs on the lowest slopes of Saba in a relatively extensive and sun-exposed zone that extends from Parish to the area between Windward Side and The Level and then north to Flat Point. The Aristida - Mitracarpus type (type 9, 48 species) is the main vegetation type with a lesser role for the Bothriochloa pertusa (type 8, 43 species) and Wedelia - Plumbago types (type 7, 64 species).

The vegetation of the Netherlands Antilles

(Stoffers, 1956) recorded the site as (Box 3):

- Dry Evergreen Formations (map in Appendices)
- Hippomane Woodland (although the text states 'In this vegetation *Batis maritima*, *Sesuvium portulacastrum*, and other halophytic species are associated with *Hippomane mancinella*. It is absent in Saba.")

Box 3 Extract on vegetation from (Stoffers, 1956) p105

> In some places, especially in the deeper guts, a mixture of several species occurs, forming a dense bush of no particular structure. Here the following species were collected: *Abrus precatorius, Achyranthes aspera, Aloe vera, Annona muricata, Antigonon leptopus, Boerhavia coccinea, Bourreria succulenta, Bryophyllum pinnatum, Bursera simaruba, Caesalpinia bonduc, Calotropis procera, Capparis baducca, C. flexuosa, Casearia decandra, Cassia bicapsularis, Cissus sicyoides, Citharexylum spinosum, Clerodendron aculeatum, Croton flavens, C. lobatus, Cyperus planifolius, Cuscuta americana, Indigofera suffruticosa, Jatropha gossypifolia, Lantana involucrata, Leonotis nepetaefolia, Leucaena glauca, Melicocca bijuga, Melocactus, Morisonia americana, Opuntia dillenii, O. triacantha, Pectis febrifuga, Ricinus communis, Solanum argillicolum, S. racemosum, Spermacoce confusa, Plumbago scandens, Rauwolfia lamarckii, Tabebuia pallida, Tamarindus indica, Tecoma stans, Thespesia populnea, Urechites lutea* and *Vinca rosea.*
>
> In Compagnie's Gut, Tom's Gut and Swanna Gut [9], the vegetation consists of a shrub layer about 1 m high, *Lantana camara, L. involucrata, Croton flavens, Wedelia jacquinii* and *Mitracarpus polycladus* being the predominant species, and varying in abundance from point to point: Croton thickets. The total cover ranges from 75 to 100%. *Annona montana, Calotropis procera, Casearia decandra* and *Rauwolfia lamarckii* rise above this shrub layer. Other species in the shrub layer are *Sida cordifolia, Solanum racemosum, Indigofera suffruticosa, S ida cordifolia var. althaeifoliaVi,nca rosea, Jatropha gossypifolia,* and *Eupatorium odoratum*. Some vines are present: *Plumbago scandens, Abrus precatorius,* and *Centrosema virginianum*. Herbs: *Siphonoglossa sessilis, Capraria biflora,* and *Cenchrus echinatus*. The fern *Pithyrogramme calomelanos* is found there, but is rare. Only on the higher ground and on The Flat, between Tom's Gut and Compagnie's Gut, do several scattered trees occur, *Pisonia subcordata* being the most frequent one, accompanied by *Tabebuia pallida, Citharexylum spinosum* and *Comocladia ilicifolia*.

New York Botanical Garden

Extensive species lists and limited information on where the species were found.

Threats

Overgrazing / Habitat loss

Most wilderness areas of Saba are overgrazed by free-roaming goats. Highest livestock densities are in the more vulnerable coastal areas, including the southern zone which also has poor soil conditions. The areas could recover with the exclusion of goats, providing a natural barrier to erosion (de Freitas et al., 2016).

Invasive species

Invasive species of insects have wiped out almost all local white cedar (*Tabebuia heterophylla*) and Opuntia cacti along the coast, with the area to the south of St Johns being identified as an important site for these species (de Freitas et al., 2016). For these reasons, the conservation status of the dry forests has been evaluated as "very unfavourable ("State of Nature in the Dutch Caribbean: Saba and the Saba Bank," 2020) BIONEWS 24.

Climate and global warming

A summary of the likely impacts of climate change can be found in "Climate change effects on the biodiversity of the BES islands" (Debrot and Bugter, 2010). An extract is included in Box 4.

Box 4 Impacts of climate change, extract from (Debrot and Bugter, 2010) p11

Expected climate changes for this century

Air and sea surface temperatures
According to the Small Islands section of the IPCC fourth assessment report, temperatures in the Caribbean region are expected to increase between 1.4 to 3.2 °C this century

Tropical storms and hurricanes
Globally a likely increase (> 66%) in hurricane intensity with larger peak wind speeds and heavier precipitation (IPCC, 2007b) is predicted. Storm surge height is associated with hurricane intensity and is therefore also likely to increase. The range of inundation and capacity for coastal erosion will increase even more as the sea level rises. The same will be true for tsunamis (Simpson et al., 2009).

Extreme weather events (floods and droughts)
The number of flood events is expected to increase; the picture for droughts is unclear regionally.

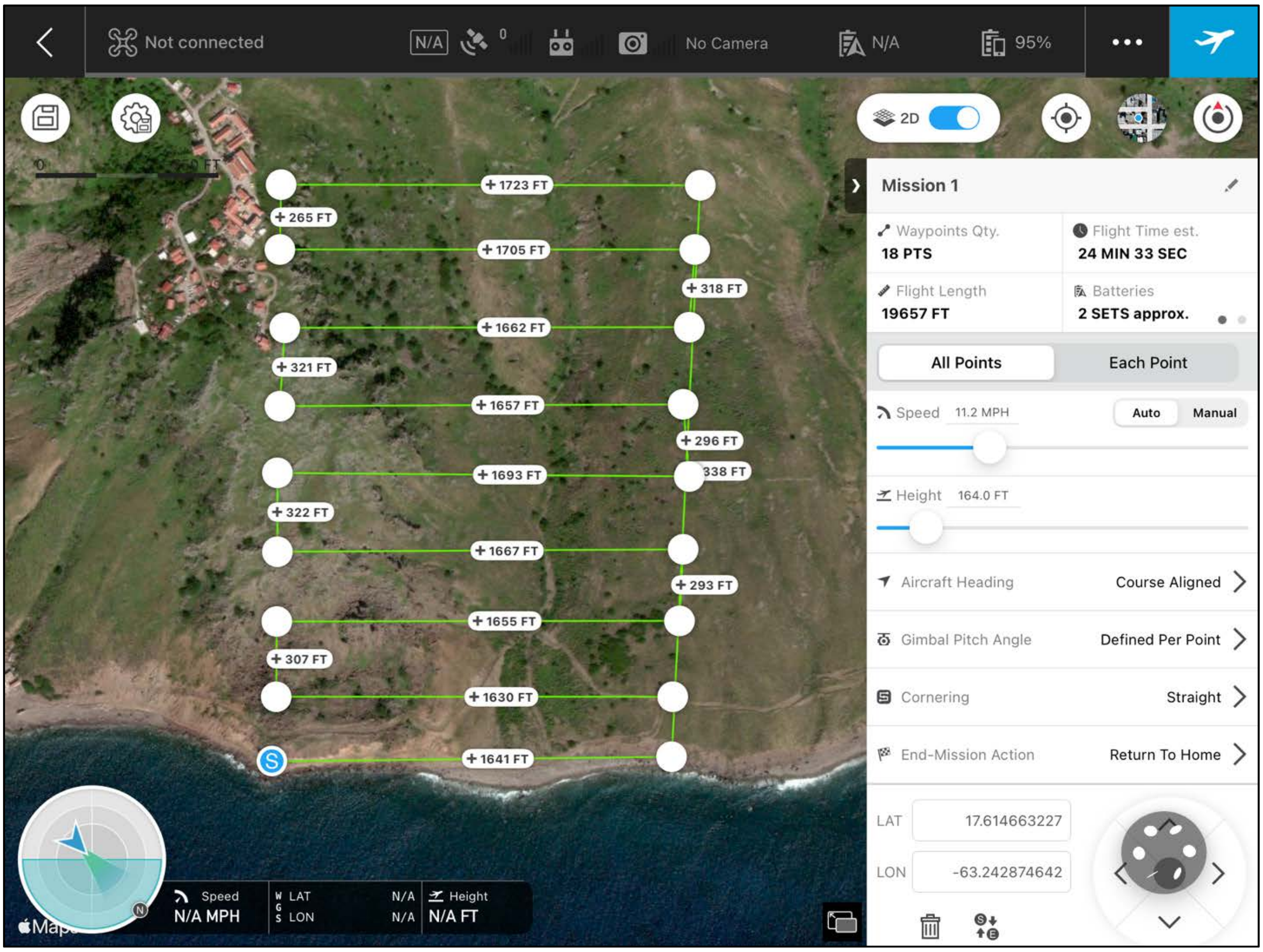
A rise in extreme weather events with high rainfall is projected to happen across the Caribbean, as a result of a projected increase in both the storm tracks passing through or near each country. Research has shown Hurricane Maria had a return period of 115 years, projecting this to a 1.5 ◦C warmer world a similar hurricane rainfall event would become a one in 75-year event and a one in 43-year event for the 2 ◦C scenario (Vosper et al., 2020).

Field survey

The area under consideration for the vegetation survey is a rectangular area of approximately 300x350 m.

The staff of Saba conservation Foundation carried out field surveys of the area selected in the final quarter of 2020. Data collected included the circumference of tree trunks using the standard measure Diameter at Breast Height (DBH) in centimetres (which is assumed as 140cm above ground)). Tree height was also recorded for some trees. Georeferenced photographs were taken of each plant surveyed. Other data recorded includes high resolution drone imagery flown on transects crossing the site (Figure 3).

Figure 3 Drone transects recorded by Saba Conservation Foundation staff



Vegatation > dbh 30cm

A number of the survey results recorded two or more trunks. Where more than one trunk was recorded, the largest DBH was taken as the result (Table 1).

Common name	Species	#30cm – 50cm dbh	# > 50cm dbh
Acacia	-		1
Ficus	-		6
Fiddlewood, Susan Berry	*Citharexylum spinosum*		1
Gumbo Limbo	*Bursera simaruba*		8
Loblolly	*Guapira fragrans*		22
Manchineel	*Hippomane mancinella*	79	62
Quadrella	*Capparis indica*	2	14
Unidentified		62	48
Total		**143**	**162**

Table 1 Species identified by Saba Conservation Foundation staff

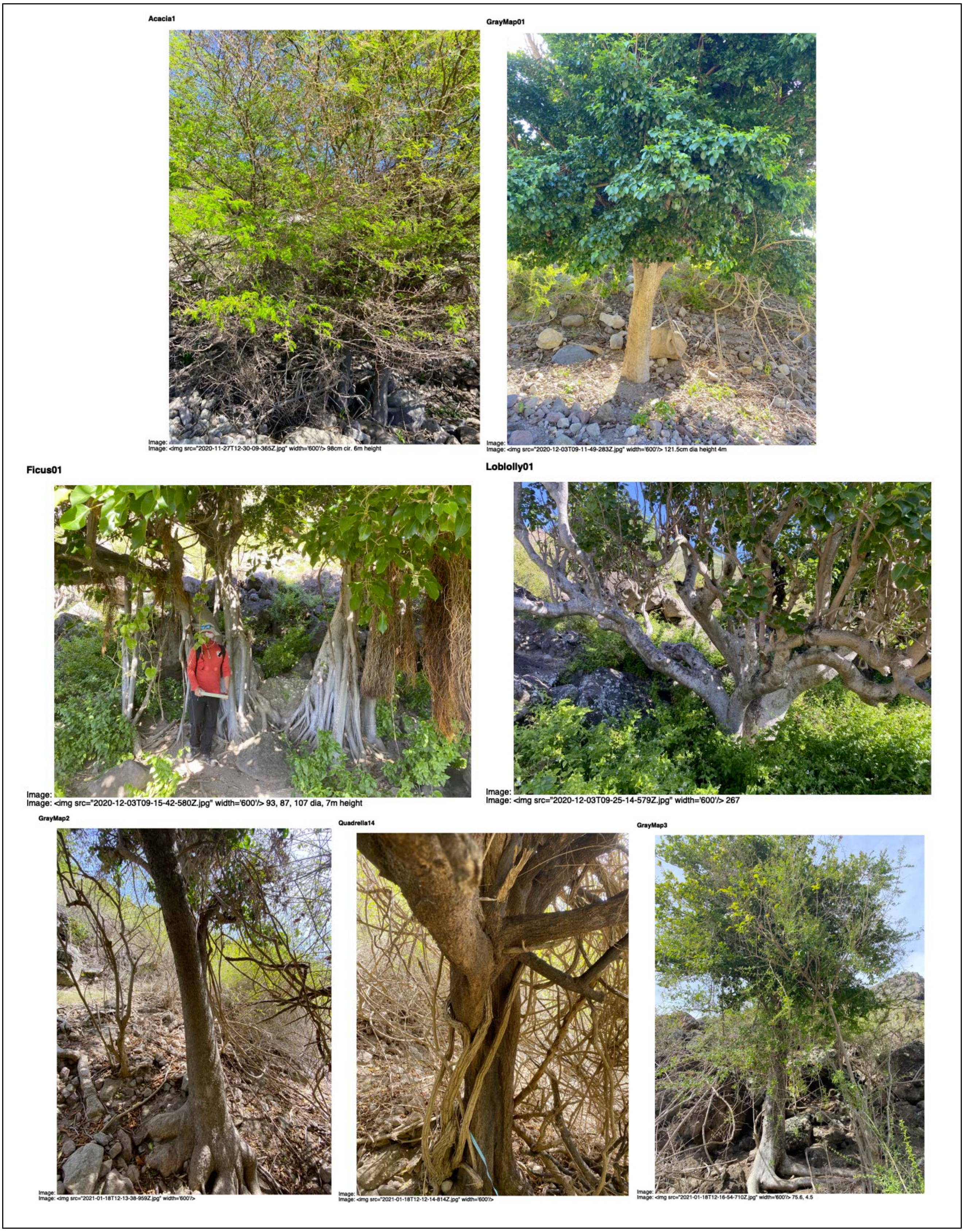
The results are plotted in Figure 4 Vegetation surveyed with 30 cm – 50 cm DBH and Figure 5 Vegetation recorded with DBH > 50cm.

Figure 4 Vegetation surveyed with 30 cm – 50 cm DBH

Figure 5 Vegetation recorded with DBH > 50cm

Figure 6 Surveyed trees near the dam construction sites and close upstream

Figure 7 Trees within the construction site of the dams



All images of the trees within the construction sites of the dams and at close upstream locations are included in the Appendix.

Other relevant species

The following information on dominant, rare and other species has been developed based on consultation with Saba Conservation Foundation staff in combination with the Landscape Ecological Map of Saba (de Freitas et al., 2016).

Dominant species

Dominant species in the area include Manchineel (*Hippomane mancinella*) which can be found forming forested areas east of the survey site (Figure 8). Other dominant species are included in Appendix. The invasive coral vine, called 'Coralita' (*Antigonon leptopus*) *is not dominant on the site but is encroaching.* Coralita typically colonizes disturbed ground and can be expected to continue to encroach on the study site.

Figure 8 Manchineel forest : drone image and images within the stand.

Rare species

Vegetation type (de Freitas et al., 2016)	7	8	9	Notes
Abrus precatorius	1			Rosary pea
Achyranthes aspera		1		Devil's horsewhip
Asplenium pumilum	1			Dwarf spleenwort
Chiococca alba	1			West Indian snow berry
Cissus verticillata	1	1		Seasonvine
Coccothrinax barbadensis	1			Silver thatch palm
Dactyloctenium aegyptium			1	Egyptian crowfoot grass
Erythroxylum havanense	1			Bracelet
Iresine diffusa	1			Jubas bush
Krugiodendron ferreum	1			Black ironwood
Lantana urticifolia		1		Nettleleaf shrub verbena
Maytenus laevigata	1			White cinnamon
Mitracarpus polyclades	1	1	1	Cana gorda girdlepod [endangered: endemic to Puerto Rico and Saba]
Myrcianthes fragrans	1			Simpson's stopper
Pityrogramma calomelanos	1		1	Silver fern
Polypodium polypodioides	1			Resurrection fern
Rhynchosia minima	1			Jumby-bean
Rivina humilis	1			Bloodberry
Ruellia tuberosa			1	Snapdragon root or sheep potato
Sida abutifolia			1	Spreading fanpetals
Solanum racemosum	1	1		Bahama nightshade
Solenostemon scutellaroides	1			Coleus
Stachytarpheta jamaicensis	1	1		Blue porterweed, more frequent in higher elevations
Stylosanthes hamata			1	Caribbean stylo
Tabernaemontana citrifolia	1			Milkwood
Teramnus labialis			1	Blue wiss
Vernonia albicaulis	1			Sanata maria
Wedelia calycina	1		1	Creeping-oxeye
Agave karatto				Agave
bromelia penguin				Pinguin
Croton flavens				Maran bush
Isotoma longiflora				Star of Bethlehem

Table 2 Rare species likely to be found in the survey area

Birds

Literature review

Birdlife International

Box 5 Extract from Important Bird Areas of the Caribbean – Saba (N Collier and Brown, 2008) p260

Of the 87 species of bird recorded from Saba, just 26 breed, and 36 are regular Neotropical migratory birds (although Saba is too small to hold significant populations of these migrants). Eight (of the 38) Lesser Antilles EBA restricted-range birds occur on the island, although none of these is endemic to Saba. A ninth restricted-range species, the Antillean Euphonia *Euphonia musica* has not been recorded on the island since 1952 and is probably extirpated. The Bridled Quail-dove *Geotrygon mystacea* may also be heading for extinction on the island, having declined dramatically over the last 10 years (*to 2008) as a result of hurricane impacts and predation.

It is for the breeding seabirds—Red-billed Tropicbird *Phaethon aethereus* and Audubon's Shearwater *Puffinus lherminieri* —that Saba is most noted. *Puffinus lherminieri* is the national bird of Saba and is familiar to residents across the island, although predation from rats and cats could be significantly impacting the population (as it could be with the population of *Phaethon aethereus*). Assessing the population of the shearwater on the island is difficult due to the extent of breeding habitat, the lack of an obvious peak breeding season (birds are known to be present between at least December and May) and the nature of the terrain (e.g. steep dirt "cliffs" that are unsuitable for rope work). The use of monitoring technology, such as autonomous audio recorders, may provide more consistent and unbiased data than nest searches or the call/playback method

Box 6 Extract from BirdLife International ("BirdLife International Datazone - Saba IBA," 2021)

The Saban population of Red-billed Tropicbirds has been estimated at 750-1,000 breeding pairs, meeting the requirement for more than 1% of the global estimated population (20,000). They can be found nesting around the entire perimeter of the island in coastal cliffs and xeric, rocky hills. Despite being the national bird of Saba and familiar to residents, the Audubon's Shearwater population is much more difficult to estimate accurately due to inconspicuous nesting habits and inadequate data. Because all coastal areas are cliffs, there is a tremendous amount of potential habitat. Indeed Lee (2000) has placed the population at 1,000 individuals based on available habitat. One shearwater was found on an egg near Sulphur Mine in February 2002. No calls were heard during 10 hours of nocturnal observations in February (Collier et al. 2002). In April 2004, two hours of nocturnal call-playback resulted in one response by a shearwater near The Bottom. In May 2004, four hours of nocturnal call-playback resulted in three responses near The Bottom and 15-20 responses at Sulphur Mine. It is possible there is no peak in breeding activity, resulting in a protracted nesting period, which would further hinder population estimates. The steep topography limits accurate nest counts as well, although numbers of flying or calling adults may be used. Although these are the only known estimates, there is sufficient evidence to conclude that Saba meets the globally important criteria for Audubon's Shearwater.

Some regionally limited species can be found in pockets of habitat along the coastal zone, these include: Green-throated Carib *Eulampis holosericeus*, Antillean Crested Hummingbird *Orthorhyncus cristatus*, Pearly-eyed Thrasher *Margarops fuscatus*, and Lesser Antillean Bullfinch *Loxigilla noctis*.

Radar Surveys for Audubon's Shearwater on Saba, Netherlands Antilles

Box 7 Extract on Audobons Shearwater from (Brown, 2014) p4

SAB5 St. Johns 14 December 2014; Elevation: 310 m; Distance From Sea: 0.61 km; Audubon's Shearwater Targets Detected: 64. The radar at this station was trained to detect shearwater activity in the area of Fort Bay and the landfill area. This area was thought to be habitat for a large portion of shearwaters (fide M. McGhee). Our radar was able to monitor birds coming off the water, the large coastal boulder field, and the large cliff faces above Fort Bay and the landfill. We detected the majority of birds flying to the cliff faces above the landfill and smaller portions of birds flying to cliff above Fort Bay as well as to the coastal boulder field.

New avifaunal records and checklist for the island of Saba, Caribbean Netherlands.

Box 8 Other birds recorded on the coast of Saba extract from (Boeken, 2018)

Notes on key species (p60)
Phaethon aethereus (**Red-billed tropicbird**)
Vous (1983) estimated a maximum of 20 pairs of Red-billed tropicbirds, but during the first decade of this century the breeding population on Saba was estimated as 750–1,000 breeding pairs, amounting to about 35% of the total West Indian population (Lee and Walsh-McGehee 2000, Walsh-McGehee 2000, Collier and Brown 2006, Lee and Mackin 2008a). More recent observations yield conservative estimates of 1,200–1,500 pairs (Geelhoed *et al.* 2013, Boeken 2016).

Puffinus lherminieri (**Audubon's shearwater**)
Audubon's shearwater populations were estimated by Lee (2000) to be 1,000 breeding pairs based on available habitat. Collier and Brown (2006) discuss some difficulties in estimating population size. Based on my own observations, the estimation of 1,000 pairs appears to be too high. My observations concur with the estimates of 15–21 pairs by Lee and Mackin (2009d) and 25 pairs by Bradley and Norton (2009).

Observations near Fort Bay

- *Himantopus mexicanus* (Black-necked Stilt)
- *Haematopus palliatus* (American Oystercatcher)
- *Charadrius semipalmatus* (Semipalmated Plover)
- *Arenaria interpres* (Ruddy Turnstone)
- *Larus delawarensis* (Ring-billed Gull)
- *Egretta thula* (Snowy Egret)
- *Passer domesticus* (House Sparrow)

Breeding success of Red-billed Tropicbirds (Phaethon aethereus) on the Caribbean island of Saba

Figure 9 St Johns colony size estimates of Red-Billed Tropicbirds (Boeken, 2016)

Table 3. Results of peak attendance counts and colony visits of adult Red-billed Tropicbirds *Phaethon aethereus* at different colonies on Saba.

Location	Attendance counts				Nest counts			Estimated colony size (number of pairs)
	Number of count days	Date maximum number	Time	Maximum number adults	Number	Area of colony counted (%)	Ratio number adult:nests	
Tent	3	24–02–2011	15:50	65	34	10–15	3.5–5.2	230–340
Great Level	1	24–02–2011	15:40	42	20	20	2.4	100
Old Booby Hill N+S	21	12–03–2011	16:15	72	107	10–12.5	3.9–4.8	860–1070
Old Booby Hill E	7	18–03–2012	16:00	150				
Pirate Cliffs	3	27–02–2011	16:10	50				120–260
St. John's Cliffs	1	04–12–2011	15:00	6				10–30

Threats

Development

The destruction and fragmentation of habitat is one of the most critical threats facing birds globally. Areas cleared for development reduce the available nesting and foraging areas for birds and the remaining patches of habitat are often too small or fragmented to sustain populations making them vulnerable to localised extinction.

Anthropogenic noise from the development process and once new developments are operational is a pervasive pollutant that decreases environmental quality by disrupting behavior vital to perception and communication of birds. Research has shown noise causes widespread, chronic stress coupled with reduced fitness within bird populations for many species (Kleist et al., 2018).

Terrestrial predatory fauna species

Saba's avifauna is impoverished, in large part due to the presence of invasive predators. Cats and rats prey on ground nesting birds, including tropicbirds. Cats are known to prey on Shearwaters, red-Billed Tropicbirds and the Bridled Quail dove, which may soon be designate as threatened; fewer and fewer numbers are being found in key areas (MacRae and De Meyer, 2020).

Field survey

The area for the bird survey is approximately 500x650 m and includes steep, inaccessible cliffs, particularly near the settlement of St. Johns, which are favoured by nesting seabirds (Figure 10).

Figure 10 Bird survey area shown in yellow.

Field observations of the birds present during the vegetation survey were carried out. Species observed included:

- Red-billed tropicbirds; SCF staff estimated observing Red Billed Tropic birds 80-100 nests on hillside near St Johns.
- Audobon's shearwater is also known to nest on the inaccessible slopes in the north east of the survey area near St Johns
- Swallows
- Zenadia doves (*Zenadia aurita*)

The Great Level has been identified as one of four important Sea Bird Nesting sites (Wulf, Saba Conservation Foundation).

Other fauna

The single endemic vertebrate is *Anolis sabanus*. The gecko *Sphaerodactylus sabanus* has a restricted range. Hunting has caused The Mountain Crab *Gecarcinus ruricola* to now be considered endangered on the island. The bat sub-species *Natalus stramineus stramineus* is endemic to Saba (N. Collier and Brown, 2008)

Species of conservation importance

The terrestrial species below have been identified as being of conservation importance and are believed to be present within the survey site. A complete terrestrial species list can be found in the Appendix, which includes orchids, bats and other species of bird that may also be found at the site. Comprehensive species list available on Parks-Work.com

Group name	*Scientific name*	English	(Key)	IBA species	Red List CR	Red List VU	CITES II	Restricted range	Island endemic	SPAW II	SPAW III	Legislation	Flagship
Plants	*Cordia nesophila*	Bastard Tobacco	**K**					1					
Plants	*Busera simaruba*	Balsam tree	**K**										
Plants	*Capparis flexuosa*	Mustard plant (family)	**K**										
Plants	*Capparis indica*	Huliba macho	**K**										
Plants	*Coccoloba uvifera*	Seagrape	**K**										
Plants - cacti	*Hylocereus lemairei*	Night-blooming Cactus	E				1						
Plants - cacti	*Hylocereus trigonus*	Strawberry Prickle	E				1						
Plants - cacti	*Melocactus intortus*	Turk's Head Cactus	**K**				1				1		
Plants - cacti	*Opuntia boldinghii*	Pickly pear	**K**				1						
Plants - cacti	*Opuntia caribaea*	Cactus sp.	E				1						
Plants - cacti	*Opuntia cochenillifera*	Cochineal cactus	E				1						
Plants - cacti	*Opuntia dillenii*	Sour Prickle	E				1						
Plants - cacti	*Opuntia elatior*	Broad Prickly Pear	E				1						
Plants - cacti	*Opuntia ficus-indica*	Indian fig	E				1						
Plants - cacti	*Opuntia stricta*	Erect Prickly Pear	E				1						
Plants - cacti	*Opuntia triacantha*	Spanish Lady	E				1						
Plants - cacti	*Rhipsalis baccifera*	Mistletoe cactus	E				1						
Birds	*Phaethon aethereus*	Red-billed Tropicbird	**K**	1								1	1
Birds	*Puffinus lherminieri*	Audubon's Shearwater	**K**	1						1		1	1
Reptiles - iguana	*Iguana delicatissima*	Lesser Antillean Iguana	**K**		1		1	1			1		
Reptiles - iguana	*Iguana iguana*	Saba Black Iguana sub species	**K**				1		1		1	1	
Reptiles - iguana	*Iguana melanoderma*	Melanistic Lesser Antilles Iguana	**K**					1					
Reptiles - lizard	*Sphaerodactylus sputator*	Island Dwarf Gecko, Least Island Gecko	E					1					
Reptiles - lizard	*Sphaerodactylus sabanus*	Saba Dwarf Gecko	E					1					
Reptiles - lizard	*Anolis sabanus*	Saban Anole lizard	**K**						1			1	1
Reptiles - lizard	*Iguana iguana sp.*	Saban Black Iguana	**K**										1
Reptiles - snake	*Alsophis rufiventris*	Red-bellied Racer	E			1		1					1

Table 3 Example species of conservation importance believed to be located within the study site

Key: Presence at site **K** = Known E = expected

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Appendices

Survey data

Diameter at Breast height plant species
Geo referenced images of vegetation 30cm-50cm DBH
Drone transects

Available on request from Parks-Work or Saba Conservation Foundation

Google Earth Files

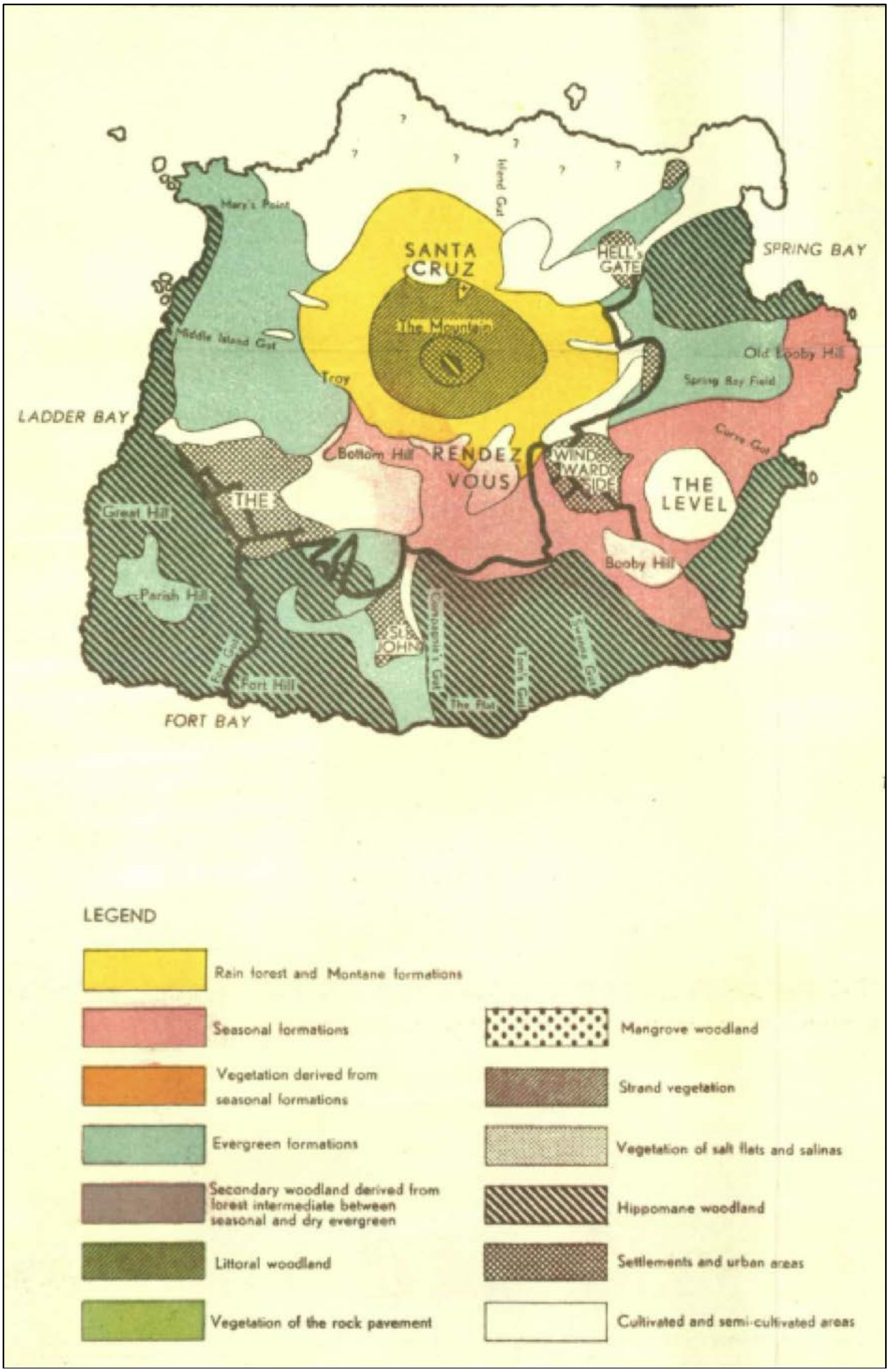
Birds survey area
Vegetation survey area
Vegetation 30cm – 50cm dbh
Vegetation > 50cm dbh

Available on request from Parks-Work or Saba Conservation Foundation

Key references / Literature Survey

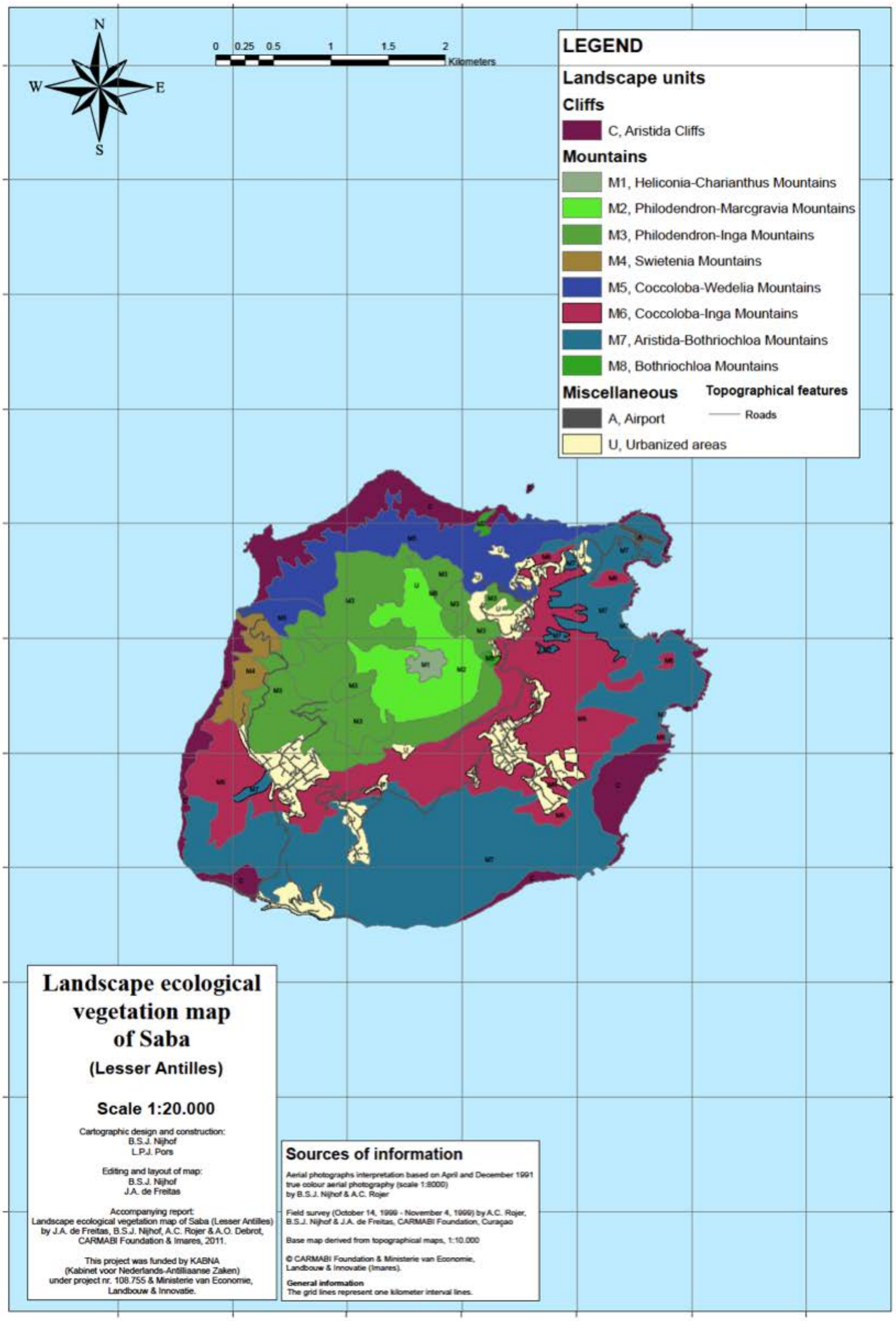
Landscape ecological vegetation map of Saba (Lesser Antilles)
Naturalis
Dutch Caribbean Biodiversity Database
New York Botanical Garden
Climate change effects on the biodiversity of the BES islands

Map: The vegetation of the Netherlands Antilles (Stoffers 1956)



(Stoffers, 1956)

Map: Landscape ecological vegetation map of Saba (Lesser Antilles) (Freitas Nijhoff, B.S.J et al., 2016)



Images of species on dam construction sites and close upstream locations.

Acacia1

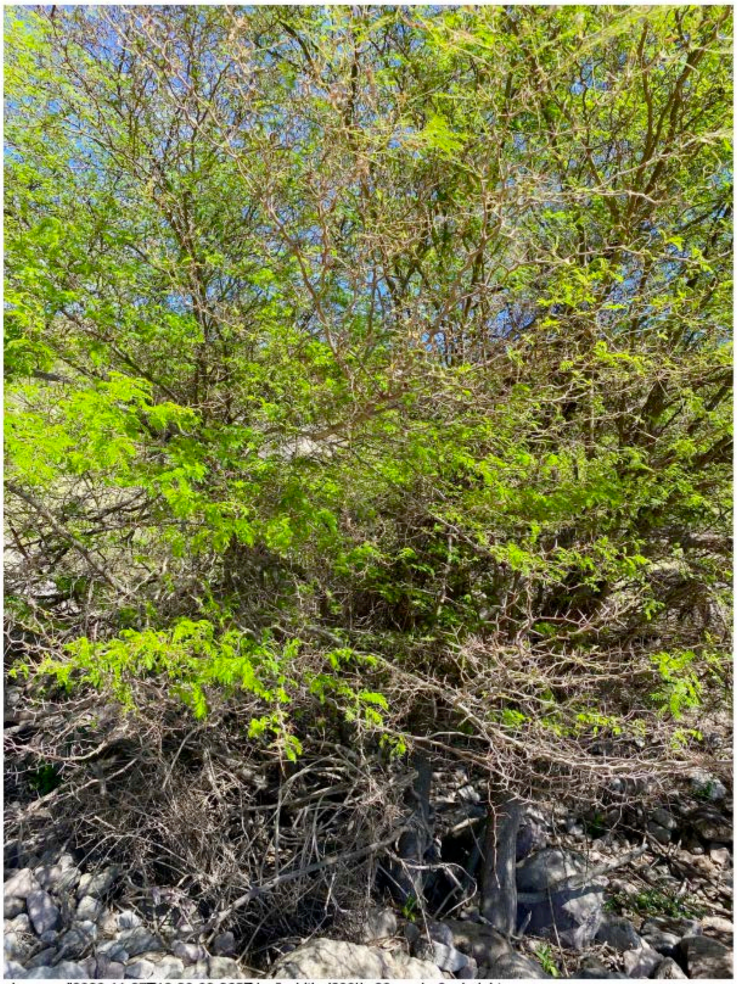


Image:
Image: 98cm cir. 6m height

GrayMap01

Image:
Image: 121.5cm dia height 4m

Ficus01

Image:
Image: 93, 87, 107 dia, 7m height

Loblolly01

Image:
Image: 267

GrayMap2

Image:
Image:

Quadrella14

Image:
Image:

GrayMap3

Image:
Image: 75.6, 4.5

GumboLimbo8

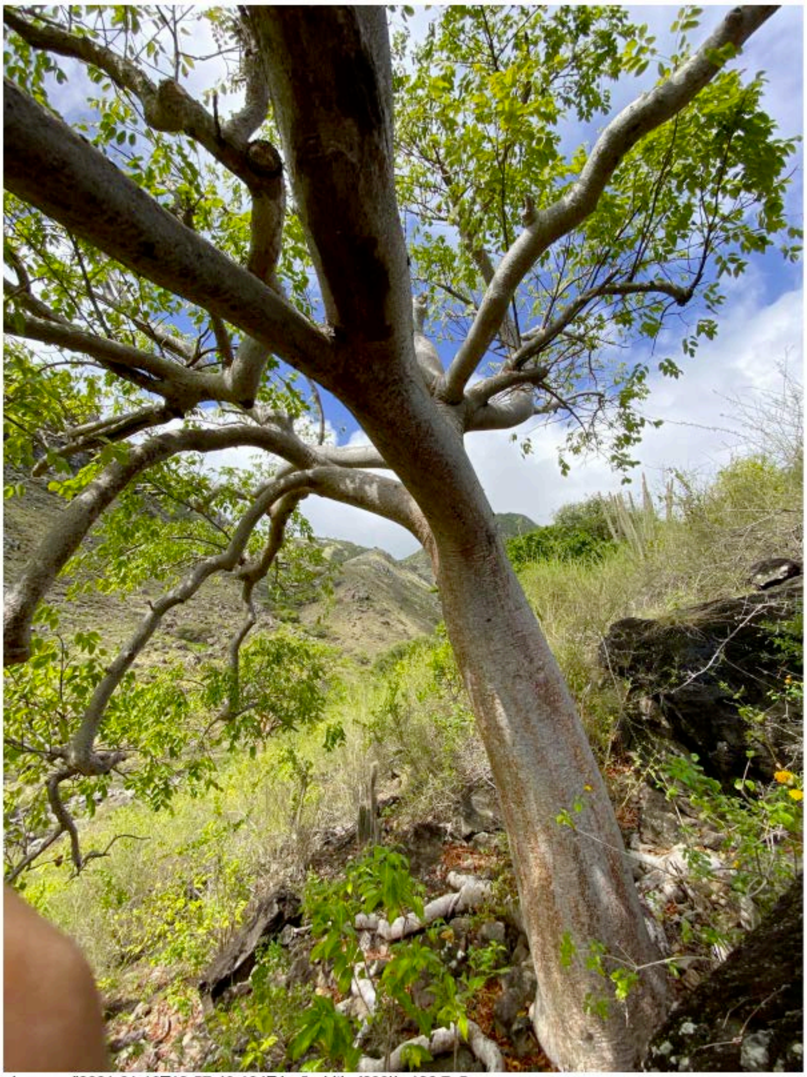


Image:
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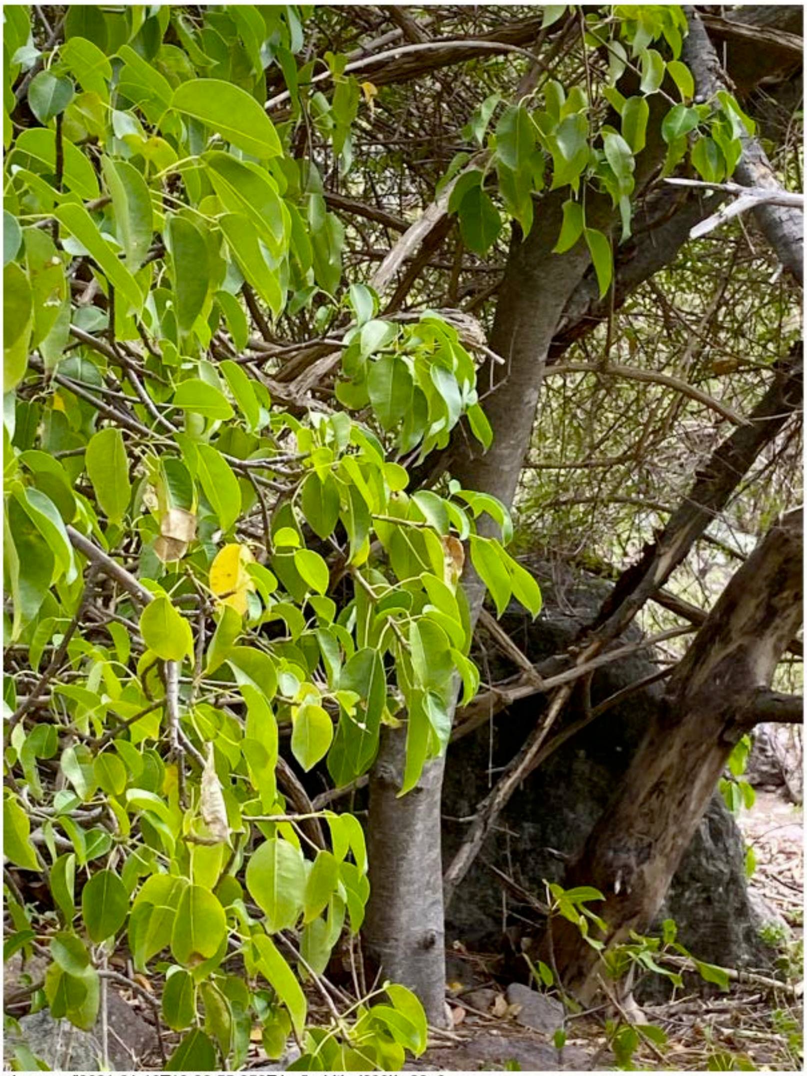
Quadrella15

Image:
Image: 95, 3

GumboLimbo6

Image:
Image: 139.1, 7

Manchineel269



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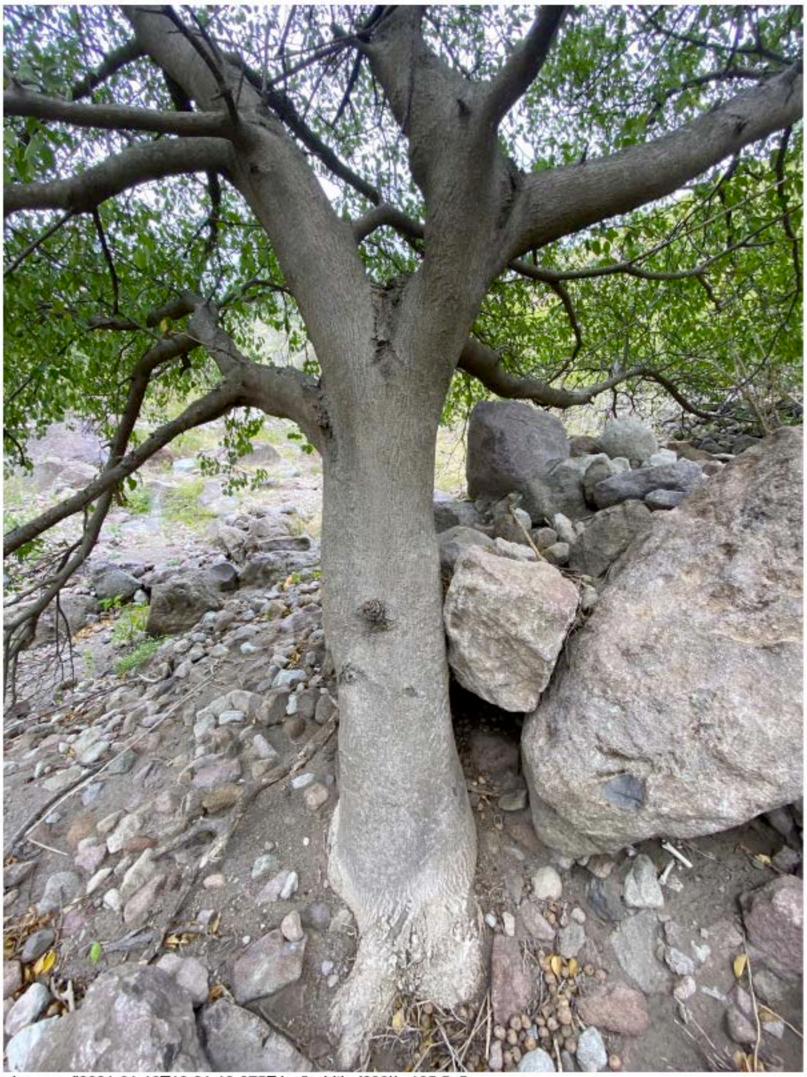
Manchineel268

Image:
Image: 46, 4

Manchineel272

Image:
Image: 70.7, 6

Manchineel271



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Manchineel270

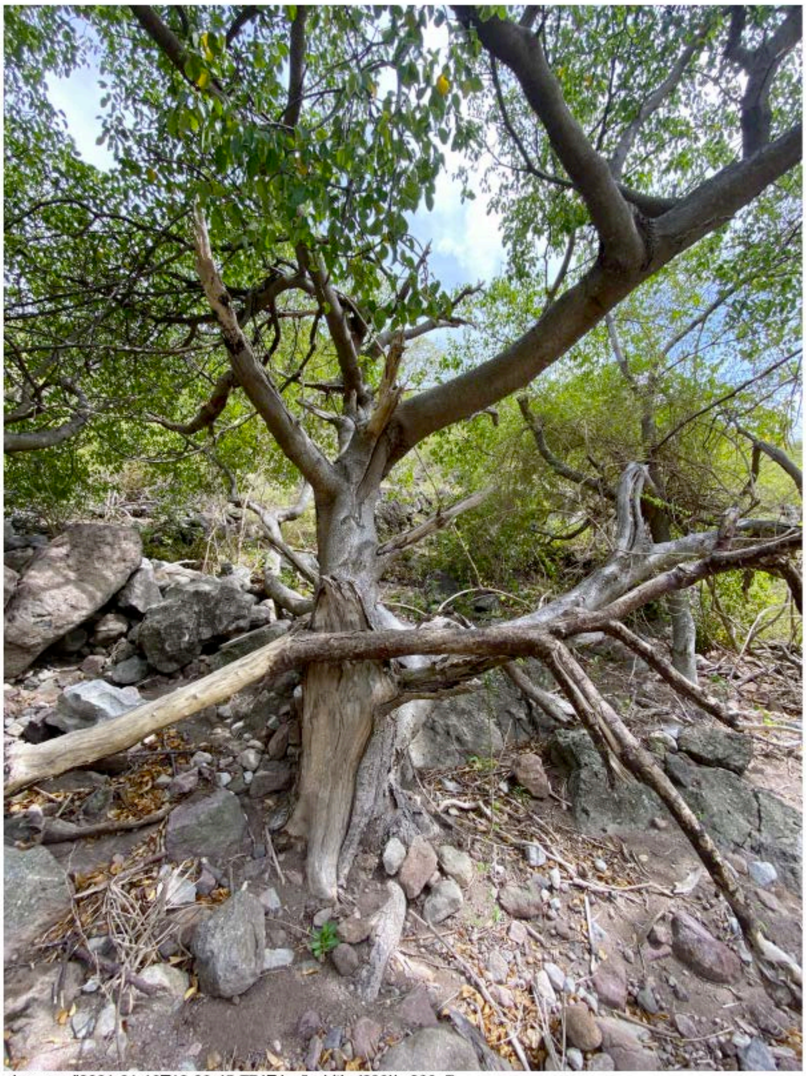

Image:
Image: 200, 7

GumboLimbo5

Image:
Image: 169.8, 4

Map important bird nesting sites

Important bird nesting sites identified by Kai Wulf, Saba Conservation Foundation

Vegetation species list

(de Freitas et al., 2016). 7,8,9 refer to the vegetation type, [Landscape ecological vegetation map of Saba.]

	7	8	9
Abrus precatorius	1		
Achyranthes aspera		1	
Allophyllus racemosus	1		
Antigonon leptopus	1		
Aristida adscensionis		1	1
Asplenium pumilum	1		
Boerhavia coccinea		1	1
Bothriochloa pertusa		1	1
Bryophyllum pinnatum	1		1
Bursera simaruba	1		
Capparis flexuosa	1		
Capparis indica	1		
Casearia decandra	1		
Catharanthus roseus			1
Catopsis floribunda	1		
Centrosema virginianum	1	1	1
Cestrum laurifolium		1	
Chamaesyce hirta			1
Cheilanthes microphylla		1	
Chiococca alba	1		
Chloris inflata		1	1
Cissus verticillata	1	1	
Citharexylum spinosum	1		
Cleome viscosa			1
Clerodendrum aculeatum	1		
Coccoloba uvifera	1		1
Coccothrinax barbadensis	1		
Commelina elegans	1	1	
Cordia nesophila	1		
Croton astroites	1	1	1
Cyperus distans			1
Dactyloctenium aegyptium			1
Daphnopsis americana	1		
Desmodium incanum		1	1
Desmodium triflorum		1	1
Digitaria ciliaris		1	1
Emilia fosbergii		1	
Erythroxylum havanense	1		
Eugenia axillaris	1		
Eugenia procera	1		
Eugenia rhombea	1		
Eupatorium odoratum		1	
Euphorbia serpens			1
Ficus citrifolia	1		
Fimbristylis dichotoma			1
Galactia dubia	1		
Guapira fragrans	1		
Gundlachia corymbosa		1	
Hylocereus trigoneus	1		
Hyptis pectinata	1		
Indigofera suffruticosa		1	1
Iresine diffusa	1		
Jasminum fluminense	1		
Jatropha gossypiifolia		1	1
Justicia sessilis	1	1	1
Krugiodendron ferreum	1		
Lantana camara	1	1	
Lantana involucrata		1	1

	7	8	9
Lantana urticifolia		1	
Lithophila muscoides			1
Malvastrum americanum			1
Mariscus capilaris		1	
Maytenus laevigata	1		
Mitracarpus polyclades	1	1	1
Momordica charantia	1	1	
Myrcianthes fragrans	1		
Opuntia triacantha		1	
Panicum trichoides	1		
Passiflora suberosa	1		
Pectis linearis			1
Peperomia myrtifolia	1		
Philodendron giganteum	1		
Phyllanthus amarus			1
Pilea microphylla	1		1
Pilea semidentata		1	
Pimenta racemosa	1		
Pisonia subcordata	1		
Pitcairnia angustifolia	1		1
Pityrogramma calomelanos	1		1
Plumbago scandens	1	1	1
Poaceae species			1
Poaceae species			1
Polypodium polypodioides	1		
Portulaca oleracea		1	1
Portulaca rubricaulis			1
Randia aculeata	1	1	
Rauvolfia viridis		1	
Rhynchosia minima	1		
Rhynchosia reticulata	1		
Rivina humilis	1		
Ruellia tuberosa			1
Salvia micrantha		1	
Senna bicapsularis	1		
Setaria setosa	1		1
Sida abutifolia			1
Sida cordifolia			1
Sida glabra		1	
Sida glomerata		1	1
Sida jamaicensis			1
Sidastrum multiflorum		1	1
Solanum racemosum	1	1	
Solenostemon scutellaroides	1		
Sporobolus pyramidatus		1	
Stachytarpheta jamaicensis	1	1	
Stylosanthes hamata			1
Tabernaemontana citrifolia	1		
Tecoma stans	1		
Teramnus labialis			1
Tournefortia hirsutissima	1		
Tragia volubilis		1	
Tragus berteronianus			1
Tridax procumbens		1	
Triumfetta semitriloba	1	1	1
Turnera ulmifolia			1
Urechites lutea		1	1
Vernonia albicaulis	1		
Wedelia calycina	1		1

Climate

(de Freitas et al., 2016) Landscape ecological vegetation map of Saba.

METEOROLOGICAL SERVICE NETHERLANDS ANTILLES & ARUBA

THE BOTTOM, SABA (17° 38'N, 63° 15' W) SUMMARY OF CLIMATOLOGICAL DATA, PERIOD 1971 -

ELEMENT		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Av. Air temperature	°C	25.7	25.3	25.7	26.6	27.4	28.1	28.1	28.5	28.5	28.2	27.4	26.3	27.2
Av. Maximum temperature	°C	28.1	27.7	28.3	29.2	30.0	30.4	30.5	30.9	30.8	30.4	29.8	28.6	29.6
Abs. Maximum temperature	°C	30.4	30.8	30.7	31.7	31.9	32.5	32.8	33.2	33.2	32.1	32.0	31.1	33.2
Av. Minimum temperature	°C	24.1	23.6	23.9	24.7	25.6	26.2	26.0	26.4	26.5	26.3	25.4	24.7	25.3
Abs. Minimum temperature	°C	20.8	20.0	21.4	22.1	22.6	23.1	21.8	22.0	22.4	22.4	22.6	21.3	20.0
Av. Air pressure (-1000)	hpa	16.9	17.3	16.6	16.0	16.4	17.2	17.1	15.2	14.0	14.3	14.4	16.0	15.9
Av. Vapour pressure	hpa	27.3	26.9	26.0	27.3	28.6	31.0	34.5	35.3	34.4	30.9	26.0	24.5	29.4
Av. Relative humidity	%	82.0	82.3	78.2	78.8	78.0	81.9	84.5	88.8	87.4	81.2	71.1	74.5	80.7
Av. Dewpoint temperature	°C	22.3	22.0	21.6	22.5	23.3	24.6	26.4	26.8	26.3	24.5	21.7	20.7	23.6
Av. Montly rainfall	mm	36.8	75.3	35.4	28.1	95.9	44.4	60.8	77.0	60.5	35.5	134.5	76.5	760.5
Av. Days with rain	≥ 1,0	10.3	10.3	6.3	4.0	6.7	5.8	5.8	6.3	7.3	3.5	10.0	9.7	7.2
Highest rainfall in 24 hours		12.6	116.8	14.8	30.6	124.8	28.4	37.4	96.8	62.2	33.4	71.2	41.6	124.8
Av. Wind speed (10m)	m/s	5.7	5.8	5.5	4.7	5.1	5.8	5.6	5.1	4.8	4.6	4.5	5.2	5.2
Av. Maximum wind speed	m/s	12.5	13.0	11.7	10.5	11.2	12.4	12.7	12.0	12.4	11.3	11.6	11.7	11.9
Strongest gust	m/s	19.6	27.3	18.0	18.0	18.0	23.2	26.8	27.3	24.2	24.7	22.2	21.6	27.3

Hurricane records

(de Freitas et al., 2016) Landscape ecological vegetation map of Saba.

Only hurricanes or tropical storms with maximum sustained surface wind speed (1 minute mean; msswp) of minimally 50 mph near the Dutch Windward Islands (St. Eustatius, Saba and St. Maarten) are listed. Hurricanes that caused considerable damage to one or more of the Dutch Windward Islands are marked with an *.

Year	**Month / day**	**Name hurricane**	**Msswp** (mph)
1956	11-Aug	Betsy	90
1959	18-Jul	Edith	50
1960	4-Sep	Donna	145*
1963	27-Oct	Helena	50
1964	22-Aug	Cleo	100
1965	28-Aug	Betsy	55
1966	26-Aug	Faith	90
1966	27-Sep	Inez	130
1975	14-Sep	Eloise	35[1]
1979	29-Aug	David	150
1979	3-Sep	Frederic	75[1]
1984	8-Nov	Klaus	75
1989	3-Aug	Dean	85
1989	17-Sep	Hugo	140*
1990	6-Oct	Klaus	70
1995	27-Aug	Iris	65
1995	5-Sep	Luis	145*
1995	15-Sep	Marilyn	95*
1996	8-Jul	Bertha	80
1998	21-Aug	Bonnie	50
1998	21-Sep	Georges	110*
1999	20-Oct	José	75*
1999	18-Nov	Lenny	115*

[1] These two events caused prolonged extensive flooding because of their associated torrential rainfall of more than 250 mm.
Source: www.meteo.cw (2014).

Tropical storms and hurricanes since 1999, Storm Carib 2020

Date			Windspeed Mph	Category	Closest point (miles)	
22	**Aug**	**2000**	**75**	**h1**	**26**	**DEBBY**
15	Sep	2004	63	ts	61	JEANNE
10	Dec	2007	40	ts	46	OLGA
16	**Oct**	**2008**	**132**	**h4**	**59**	**OMAR**
30	**Aug**	**2010**	**121**	**h3**	**59**	**EARL**
21	Aug	2011	58	ts	22	IRENE
11	Sep	2011	52	ts	57	MARIA
14	Oct	2012	52	ts	20	RAFAEL
14	**Oct**	**2014**	**92**	**h1**	**34**	**GONZALO**
06	**Sep**	**2017**	**178**	**h5**	**32**	**IRMA**
28	Aug	2019	69	ts	65	DORIAN

Terrestrial species of conservation importance

Summary table

	Red List CR	Red List EN	Red List VU	Red List NT	IBA species	CITES I	CITES II	Restricted range	Island	CMS I	CMS II	SPAW II	SPAW III	Legislation	Flagship
Plants	1	3					4	9					2	5	5
Plants - cacti							12						1		
Plants - orchids							22	8						36	
Plants Total	**1**	**3**	**0**	**0**	**0**	**0**	**38**	**17**	**0**	**0**	**0**	**0**	**3**	**41**	**5**
Birds	**1**	**1**		**2**	**16**	**1**	**11**	**20**			**33**	**7**	**3**	**15**	**5**
Amphibian								1							
Insect								28	6		1				
Insect								6	1				1		
Insect - arachnid							1	16							
Mammals - bat			1					5		1		1		9	1
Mollusc								3							
Reptiles - iguana	1						2	2					2	1	
Reptiles - lizard								2	1					1	2
Reptiles - snake			1					1							1
Other Fauna Total	**1**	**0**	**2**	**0**	**0**	**0**	**3**	**64**	**8**	**1**	**1**	**1**	**3**	**11**	**4**

Site:
1=unlikely to be found at the survey site
2= likely to be found on the site
blank = unsure

Site	**Group name**	***Scientific name***	**English**	**IBA species**	**Red List CR**	**Red List EN**	**Red List VU**	**Red List NT**	**CITES I**	**CITES II**	**CMS I**	**CMS II**	**Restricted**	**Island**	**SPAW I**	**SPAW II**	**SPAW III**	**Legislation**	**Flagship**
1	Amphibian	*Eleutherodactylus johnstonei*	Johnstone's Whistling Frog, Johnstone's Robber Frog										1						
2	Birds	*Phaethon aethereus*	Red-billed Tropicbird	1														1	1
2	Birds	*Puffinus lherminieri*	Audubon's Shearwater	1												1		1	1
	Birds	*Pterodroma hasitata*	Black-capped Petrel			1										1			
	Birds	*Pterodroma caribbaea*	Jamaican petrel		1								1						
	Birds	*Larus atricilla*	Laughing Gull	1															
	Birds	*Pelecanus occidentalis*	Brown Pelican	1												1			
	Birds	*Sterna anaethetus*	Bridled Tern	1															
	Birds	*Sterna dougallii dougallii*	Roseate Tern	1								1				1			
	Birds	*Thalasseus acuflavidus subsp. eurygnathus*	Sandwich Tern/Cayenne	1															

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	Birds	*Allenia fusca*	Scaly Breasted Thrasher										1					1	
	Birds	*Anas clypeata*	Northern shoveler duck									1							
	Birds	*Anas crecca*	Green-winged Teal									1							
	Birds	*Anas discors*	Blue-winged Teal									1							
	Birds	*Arenaria interpres*	Ruddy Turnstone									1							
	Birds	*Aythya affinis*	Lesser Scaup									1							
	Birds	*Aythya collaris*	Ring-necked Duck									1							
	Birds	*Buteo jamaicensis*	Red-tailed Hawk							1									
	Birds	*Calidris alba*	Sanderling									1							
	Birds	*Calidris fuscicollis*	White-rumped Sandpiper									1							
	Birds	*Calidris mauri*	Western Sandpiper									1							
	Birds	*Calidris melanotos*	Pectoral Sandpiper									1							
	Birds	*Calidris minutilla*	Least Sandpiper									1							
	Birds	*Calidris pusilla*	Semipalmated Sandpiper									1							
	Birds	*Caracara cheriway*	Northern Crested Caracara							1						1			
	Birds	*Catoptrophorus semipalmatus*	Willet									1							
	Birds	*Charadrius alexandrinus*	Snowy Plover									1							
	Birds	*Charadrius semipalmatus*	Semipalmated Plover									1							
	Birds	*Charadrius vociferus*	Killdeer									1							
	Birds	*Cinclocerthia ruficauda*	Brown Trembler	1									1			1		1	1
	Birds	*Circus cyaneus*	Hen harrier, Marsh hawk, Northern harrier							1									
	Birds	*Coereba flaveola*	Bananaquit										1						
	Birds	*Columba leucocephala*	White-crowned Pigeon														1		
	Birds	*Columbina passerina*	Common Ground Dove										1					1	
	Birds	*Dendrocygna bicolor*	Fulvous Whistling-duck									1					1		
	Birds	*Dendrocygna viduata*	White-faced Whistling Duck									1							
	Birds	*Elaenia martinica*	Caribbean Elaenia	1									1					1	
	Birds	*Elanoides forficatus*	Swallow-tailed Kite							1		1							
	Birds	*Elanus leucurus*	White-tailed Kite							1		1							
	Birds	*Eulampis holosericeus*	Green-throated Carib	1						1			1					1	
	Birds	*Eulampis jugularis*	Purple-throated Carib	1						1			1					1	
	Birds	*Euphonia musica*	Lesser Antillean Euphonia										1						
	Birds	*Falco peregrinus*	Peregrine Falcon						1			1				1			
	Birds	*Falco sparverius*	American Kestrel							1		1							1
	Birds	*Gallinago gallinago*	Wilsons Snipe									1							
	Birds	*Geotrygon mystacea*	Bridled Quail-dove	1									1					1	1
	Birds	*Glaucis hirsutus*	Rufous-breasted Hermit							1									
	Birds	*Limnodromus griseus*	Short-billed Dowitcher									1							

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	Birds	*Loxigilla noctis*	Lesser Antillean Bullfinch	1									1						
	Birds	*Magarops fuscus*	Scaly-breasted Thrasher	1															
	Birds	*Margarops fuscatus*	Pearly-eyed Thrasher	1				1					1						
	Birds	*Mniotilta varia*	Warbler															1	
	Birds	*Numenius phaeopus*	Whimbrel									1							
	Birds	*Orthorhyncus cristatus*	Antillean Crested Hummingbird	1						1			1					1	
	Birds	*Passerina cyanea*	Indigo Bunting															1	
	Birds	*Patagioenas leucocephala*	White-crowned pigeon					1									1		
	Birds	*Patagioenas squamosa*	Scaly-naped Pigeon															1	
	Birds	*Pluvialis dominica*	American Golden Plover									1							
	Birds	*Pluvialis squatarola*	Grey Plover									1							
	Birds	*Podilymbus podiceps*	Pied-billed Grebe										1						
	Birds	*Progne dominicensis*	Caribbean Martin															1	
	Birds	*Quiscalus lugubris*	Carib Grackle										1						
	Birds	*Sarkidiornis melanotos*	Comb Duck							1		1							
	Birds	*Setophaga petechia*	Mangrove Warbler										1						
	Birds	*Tringa flavipes*	Lesser Yellowlegs									1							
	Birds	*Tringa macularia*	Spotted Sandpiper									1							
	Birds	*Tringa melanoleuca*	Greater Yellow legs									1							
	Birds	*Tryngites subruficollis*	Buff-brested sandpiper																
	Birds	*Tyrannus dominicensis*	Grey Kingbird										1						
	Birds	*Vanellus chilensis*	Southern lapwing									1							
	Birds	*Vireo altiloquus*	Barbados Black-whiskered Vireo										1						
	Birds	*Wallengrenia ophites*	Fiery Broken-dash										1						
	Birds	*Wilsonia citrina*	Warbler															1	
	Birds	*Zenaida aurita*	Zenaida Dove										1						
	Birds	*Ardea herodias*	Great Blue Heron																
	Birds	*Bubulcus ibis*	Waestern Cattle Egret																
	Birds	*Egretta thula*	Snowy Egret																
	Birds	*Egretta caerulea*	Little Blue Heron																
	Birds	*Nyctanassa violacea*	Yellow-crowned Night Heron, Crabeater																
	Insect	*Aedes busckii*	Mosquito										1						
	Insect	*Alepia apexalba*	Moth/sand fly											1					
	Insect	*Allograpta limbata*	Flower fly										1						
	Insect	*Amphiacusta sanctaecrucis*	Cricket										1						
	Insect	*Antillicharis naskreckii*	Cricket											1					
	Insect	*Antillicharis sabaensis*	Cricket											1					

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	Insect	*Ascia monuste*	Great southern white butterfly										1						
	Insect	*Caribacusta saba*	Cricket										1						
	Insect	*Chelonarium pilosellum*	Beetles										1						
	Insect	*Chrysobothris sabae*	Jewel beetle											1					
	Insect	*Conoderus bifoveatus*	Beetles										1						
	Insect	*Corticochernes sabae*	Pseudoscorpions											1					
	Insect	*Cycloptilum eustatiensis*	Cricket										1						
	Insect	*Danaus plexippus*	Monarch butterfly									1							
	Insect	*Dryas iulia*	Butterfly										1						
	Insect	*Ecyrus hirtipes*	Beetles										1						
	Insect	*Elaphidion glabratum*	Elaphidion Longhorn										1						
	Insect	*Electrostrymon angerona*	Angerona Hairstreak										1						
	Insect	*Glutophrissa drusilla*	Tropical White Butterfly										1						
	Insect	*Holopsis pellucidus*	Beetles										1						
	Insect	*Lagocheirus araneiformis*	Beetles										1						
	Insect	*Lithargyrus guadeloupensis*	Beetles										1						
	Insect	*Lophoscutus geijskesi*	Assasin bug											1					
	Insect	*Microcentrum decoratum*	Katydid										1						
	Insect	*Microcentrum incarnatum*	Katydid										1						
	Insect	*Neoclytus araneiformis*	Beetles										1						
	Insect	*Nesonotus tricornis*	Forest Katydid										1						
	Insect	*Ocyptamus cylindricus*	Flower fly										1						
	Insect	*Oecanthus allardi*	Cricket										1						
	Insect	*Psyllobora lineola*	Beetles										1						
	Insect	*Schistocerca nitens*	Cricket										1						
	Insect	*Sphingonotus haitensis*	Grasshopper										1						
	Insect	*Styloleptus posticalis*	Beetle										1						
	Insect	*Urbanus obscurus*	Dark Longtail Butterfly										1						
	Insect	*Urgleptes cobbeni*	Beetle										1						
	Insect	*Antillicharis fulvescens*	Cricket										1				1		
	Insect	*Dicrepidius ignotus*	Click beetle										1						
	Insect	*Euconnus gouadeloupensis*	Beetles										1						
	Insect	*Laurellia saba*	Cricket											1					
	Insect	*Laurepa saba*	Cricket																
	Insect	*Leptotes cassius*	Cassius Blue butterfly										1						
	Insect	*Selenophorus parumpunctatus*	Beetles										1						

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	Insect	*Zeadalopus antiguensis*	Beetles										1						
	Insect - arachnid	*Anasaitis banksi*	Spiders										1						
	Insect - arachnid	*Camillina nevis*	Spiders										1						
	Insect - arachnid	*Centruroides barbudensis*	Scorpion										1						
	Insect - arachnid	*Chrysometa eugeni*	Spiders										1						
	Insect - arachnid	*Cyrtognatha simoni*	Spiders							1			1						
	Insect - arachnid	*Hahnia naguaboi*	Spiders										1						
	Insect - arachnid	*Hentzia whitcombi*	Spiders										1						
	Insect - arachnid	*Heteroonops saba*	Spiders										1						
	Insect - arachnid	*Lyssomanes portoricensis*	Spiders										1						
	Insect - arachnid	*Modisimus montanus*	Spiders										1						
	Insect - arachnid	*Neostasina bicolor*	Spiders										1						
	Insect - arachnid	*Scaphioides nitens*	Spiders										1						
	Insect - arachnid	*Scytodes dissimulans*	Spiders										1						
	Insect - arachnid	*Selenops souliga*	Spiders										1						
	Insect - arachnid	*Theridion ricense*	Spiders										1						
	Insect-arachnid	*Beata octopunctata*	Spiders										1						
2	Mammals - bat	*Ardops nichollsi*	Antillean Tree Bat										1					1	
2	Mammals - bat	*Ardops nichollsi subsp. montseratensis*	Antillean Tree Bat																
2	Mammals - bat	*Artibeus jamaicensis*	Jamaican Fruit Bat															1	1
2	Mammals - bat	*Brachyphylla cavernarum*	Antillean Fruit-eating Bat										1					1	
2	Mammals - bat	*Molossus molossus*	Velvety free-tailed bat															1	
2	Mammals - bat	*Monophyllus plethodon*	Insular Single-leaf Bat										1					1	
2	Mammals - bat	*Monophyllus plethodon subsp. Luciae*	Insular Single-leaf Bat										1					1	

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2	Mammals - bat	*Natalus stramineus*	Greater Funnel-eared Bat				1						1					1	
2	Mammals - bat	*Tadarida brasiliensis*	Mexican Free-tailed Bat								1					1		1	
2	Mammals - bat	*Tadarida brasiliensis subsp.antillularum*	Brazilian Free-tailed Bat															1	
	Mollusc	*Amphibulima patula*	Terrestrial Mollusc										1						
	Mollusc	*Bulimulus diaphanus*	Terrestrial Mollusc										1						
	Mollusc	*Opeas octogyrum*	Terrestrial Molluscs										1						
1	Plants	*Swietenia mahagoni*	West Indian mahogany			1				1								1	
1	Plants	*Ctenitis meridionalis*	Wood fern sp										1					1	
1	Plants	*Cyathea antilliana*	Tree fern															1	1
1	Plants	*Cyathea arborea*	Tree fern							1								1	1
1	Plants	*Freziera undulata*	Mountain Mahogany															1	1
2	Plants	*Busera simaruba*	Balsam tree																
2	Plants	*Capparis flexuosa*	Mustard plant (family)																
2	Plants	*Capparis indica*	Huliba macho																
2	Plants	*Coccoloba uvifera*	Seagrape																
2	Plants	*Cordia nesophila*	Bastard Tobacco										1						
	Plants	*Guaiacum officinale*	Common Lignum Vitae			1				1							1		
	Plants	*Nectandra krugii*	Black Sweet Wood			1													
	Plants	*Galactia longiflora*	Legume sp.. - shrub		1					1			1				1		
	Plants	*Begonia retusa*	Begonia										1						
	Plants	*Cakile lanceolata*	Mustard plant (family)																
	Plants	*Canavalia rosea*	Sea Pea																
	Plants	*Celtis iguanaea*	Snaky																
	Plants	*Chromolaena macrantha*	Daisy sp.										1						
	Plants	*Cissampelos pareira*	Velvet leaf																
	Plants	*Clusia major*	Wild Balsam Tree										1						
	Plants	*Datura stramonium*	Fireweed																
	Plants	*Guapira fragrans (Pisonia fragans)*	Black Lobolly Tree																
	Plants	*Justicia eustachiana*	Black mangrove										1						
	Plants	*Liverwort species*	Liverworts																
	Plants	*Mitracarpus polycladus*	Cana gorda girdlepod										1						
	Plants	*Moss species*	Moss																1
	Plants	*Morisonia americana*	Wild Mesple, Rat Apple																
	Plants	*Phoradendron trinervium*	Angled mistletoe																
	Plants	*Pluchea carolinensis*	Cattle tongue																
	Plants	*Rudbeckia hirta*	Black-eyed Susan																1
	Plants	*Schoepfia schreberi*	Gulf Graytwig																
	Plants	*Sesuvium portulacastrum*	Sea-purslane																

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	Plants	*Spondias mombin*	Yellow mombin, Hog plum, Yellow plum																
	Plants	*Strumpfia maritima*	Strumpfia																
	Plants	*Tetrazygia discolor*	Glory bush, Glory tree, princess flowers										1						
	Plants	*Tournefortia volubilis*	Twining Sea-lavender																
2	Plants - cacti	*Hylocereus lemairei*	Night-blooming Cactus							1									
2	Plants - cacti	*Hylocereus trigonus*	Strawberry Prickle							1									
2	Plants - cacti	*Melocactus intortus*	Turk's Head Cactus							1							1		
2	Plants - cacti	*Opuntia boldinghii*	Pickly pear							1									
2	Plants - cacti	*Opuntia caribaea*	Cactus sp.							1									
2	Plants - cacti	*Opuntia cochenillifera*	Cochineal cactus							1									
2	Plants - cacti	*Opuntia dillenii*	Sour Prickle							1									
2	Plants - cacti	*Opuntia elatior*	Broad Prickly Pear							1									
2	Plants - cacti	*Opuntia ficus-indica*	Indian fig							1									
2	Plants - cacti	*Opuntia stricta*	Erect Prickly Pear							1									
2	Plants - cacti	*Opuntia triacantha*	Spanish Lady							1									
2	Plants - cacti	*Rhipsalis baccifera*	Mistletoe cactus							1									
	Plants - orchids	*Arachnis flos-aeris*	Spider Orchid															1	
	Plants - orchids	*Brassavola cucullata*	Rats Tail Orchid							1								1	
	Plants - orchids	*Cranichis muscosa*	Cypress-knee Helmet Orchid															1	
	Plants - orchids	*Cyclopogon cranichoides*	Green Ladies' Tresses															1	
	Plants - orchids	*Encyclia fragrans*	Orchid							1								1	
	Plants - orchids	*Epidendrum anceps*	Brown epidendrum, Dingy-flowered epidendrum							1								1	
	Plants - orchids	*Epidendrum antillanum*	Orchid							1								1	
	Plants - orchids	*Epidendrum ciliare*	Eyelash orchid							1								1	
	Plants - orchids	*Epidendrum kraenzlinii*	Orchid							1								1	
	Plants - orchids	*Epidendrum pallidiflorum*	Orchid										1					1	
	Plants - orchids	*Epidendrum paniculatum*	Orchid															1	
	Plants - orchids	*Epidendrum patens*	West Indian Star Orchid										1					1	
	Plants - orchids	*Epidendrum radicans*	Fire Star orchid															1	
	Plants - orchids	*Epidendrum secundum*	Orchid							1								1	
	Plants - orchids	*Epidendrum strobiliferum*	Orchid							1								1	
	Plants - orchids	*Ertyhrodes plantaginea*	Orchid							1								1	
	Plants - orchids	*Habenaria monorrhiza*	Tropical Bog Orchid															1	

Site	Group name	*Scientific name*	English	IBA species	Red List CR	Red List EN	Red List VU	Red List NT	CITES I	CITES II	CMS I	CMS II	Restricted	Island	SPAW I	SPAW II	SPAW III	Legislation	Flagship
	Plants - orchids	*Jacquiniella globosa*	Orchid							1								1	
	Plants - orchids	*Maxillaria coccinea*	Scarlet flame orchid							1								1	
	Plants - orchids	*Mesadenus lucayanus*	Copper Ladies' Tresses							1								1	
	Plants - orchids	*Microchilus hirtellus*	Orchid							1								1	
	Plants - orchids	*Oeceoclades maculata*	Monk Orchid															1	
	Plants - orchids	*Oncidium leiboldii*	Orchid							1								1	
	Plants - orchids	*Ornithidium inflexum*	Flame Orchid										1					1	
	Plants - orchids	*Polystachia concreta*	Orchid							1								1	
	Plants - orchids	*Polystachya foliosa*	Orchid							1								1	
	Plants - orchids	*Ponthieva petiolata*	Shadow Witch										1					1	
	Plants - orchids	*Psilochilus macrophyllus*	Raggedlip Orchid															1	
	Plants - orchids	*Psychilis correllii*	Orchid, Correll's Psychilis							1			1					1	
	Plants - orchids	*Spathoglottis plicata*	Philippine Ground Orchid															1	
	Plants - orchids	*Spiranthes lanceolata*	Orchid							1								1	
	Plants - orchids	*Tetramicra elegans*	Orchid							1								1	
	Plants - orchids	*Tolumnia leiboldii*	Leibold's Tolumnia															1	
	Plants - orchids	*Tolumnia prionochila*	Tropical Dancing Lady Orchid															1	
	Plants - orchids	*Tolumnia urophylla*	Orchid, Dancing Lady							1			1					1	
	Plants - orchids	*Triphora surinamensis*	Orchid										1					1	
	Plants - orchids	*Epidendrum difforme*	Orchid							1			1						
	Plants - orchids	*Microchilus plantagineus*	Orchid							1									
2	Reptiles - iguana	*Iguana delicatissima*	Lesser Antillean Iguana		1					1			1				1		
2	Reptiles - iguana	*Iguana iguana*	Green Iguana, Saba Black Iguana sub species							1							1	1	
2	Reptiles - iguana	*Iguana melanoderma*	Melanistic Lesser Antilles Iguana										1						
2	Reptiles - lizard	*Sphaerodactylus sputator*	Island Dwarf Gecko, Least Island Gecko										1						
2	Reptiles - lizard	*Sphaerodactylus sabanus*	Saba Dwarf Gecko										1						
2	Reptiles - lizard	*Anolis sabanus*	Saban Anole lizard											1				1	1
2	Reptiles - lizard	*Iguana iguana sp.*	Saban Black Iguana																1
2	Reptiles - snake	*Alsophis rufiventris*	Red-bellied Racer				1						1						1

2b: Marine survey on protected coral species, Saba Conservation Foundation

Annex 2b: Results marine survey Black Rocks

Table 1: Summary inventoried species

Abbreviation specie	Name	Status	Totals
OFAV	*Orbicella faveolata*	Endangered	187 (50 %)
DCYL	*Dendogyra cylindrus*	Vulnerable	14 (4 %)
APAL	*Acropora palmata*	Critically endangered	118 (32 %)
ACER	*Acropora cervicornis*	Critically endangered	1 (0 %)
MCAV	*Montastrea cavernosa*	Least concern	17 (5 %)
OANN	*Orbicella annularis*	Endangered	34 (9 %)

Table 2: Overview determination and location of species in assessed area

POINT ID			UTM20N		Species and photos							
Survey	Point	Point ID	mE	mN	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
1	1	1.1	474923.5	1947356.3	OANN							
1	2	1.2	474900.5	1947352.7	DCYL							
1	3	1.3	474900.5	1947354.6	MCAV							
1	4	1.4	474847.5	1947363.8	OANN							
1	5	1.5	474842.2	1947363.8	OANN							
1	6	1.6	474826.3	1947367.5	MCAV							
1	7	1.7	474803.3	1947371.3	DCYL							
1	8	1.8	474785.6	1947375.0	ACER							
1	9	1.9	474769.7	1947406.3	OANN							
2	1	2.1	474223.3	1947366.5	MCAV							
2	2	2.2	474235.7	1947373.8	MCAV							
2	3	2.3	474262.2	1947384.8	MCAV							
2	4	2.4	474281.7	1947395.9	APAL	MCAV	MCAV					
2	5	2.5	474288.8	1947403.3	APAL	MCAV	MCAV					
2	6	2.6	474327.7	1947414.3	MCAV							
2	7	2.7	474338.3	1947429.0	MCAV	OFAV						
2	8	2.8	474361.3	1947430.8	APAL	OFAV						
2	9	2.9	474386.1	1947438.2	APAL	OANN						
2	10	2.10	474417.9	1947445.5	APAL	APAL						
2	11	2.11	474430.2	1947439.9	APAL	MCAV						
2	12	2.12	474458.6	1947445.4	APAL	APAL						
2	13	2.13	474490.4	1947441.7	OFAV							
2	14	2.14	474502.8	1947452.8	MCAV							
3	1	3.1	474228.7	1947493.7	OANN	APAL						
3	2	3.2	474255.2	1947486.3	OANN							
3	3	3.3	474290.7	1947497.3	OFAV	APAL	APAL					

POINT ID			UTM20N		Species and photos							
Survey	Point	Point ID	mE	mN	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
3	4	3.4	474334.8	1947488.1	APAL	APAL	APAL					
3	5	3.5	474359.7	1947506.4	APAL	APAL	APAL	APAL	APAL	APAL	OFAV	
3	6	3.6	474400.2	1947464.0	APAL	APAL	APAL	OANN				
3	7	3.7	474448.0	1947482.4	APAL	APAL	OFAV					
3	8	3.8	474462.1	1947467.5	APAL	APAL	OANN	OFAV	APAL	APAL		
3	9	3.9	474502.8	1947471.3	APAL	APAL	APAL	APAL	APAL	APAL	APAL	APAL
3	10	3.10	474522.3	1947474.9	APAL	APAL	APAL					
3	11	3.11	474548.8	1947473.0	OANN	OFAV	APAL	APAL	OANN			
3	12	3.12	474573.5	1947460.1	OANN	APAL	APAL	APAL	OFAV			
3	13	3.13	474598.3	1947449.0	OANN							
3	14	3.14	474607.1	1947456.3	APAL	APAL						
4	1	4.1	474552.2	1947417.6	OFAV	OFAV	OFAV	OANN				
4	2	4.2	474564.6	1947419.5	OFAV							
4	3	4.3	474573.4	1947415.8	MCAV							
4	4	4.4	474582.3	1947412.1	OFAV	MCAV	OFAV					
4	5	4.5	474589.3	1947415.8	OFAV							
4	6	4.6	474601.8	1947413.9	OFAV							
4	7	4.7	474612.4	1947417.6	OFAV							
4	8	4.8	474619.5	1947402.8	APAL							
4	9	4.9	474626.5	1947408.4	OANN	OANN						
4	10	4.10	474633.6	1947410.2	OFAV							
4	11	4.11	474633.6	1947413.9	OFAV	OFAV	OANN					
4	12	4.12	474644.2	1947412.0	OANN	OANN	OANN					
4	13	4.13	474656.6	1947430.5	MCAV							
4	14	4.14	474674.2	1947428.6	OANN	MCAV						
4	15	4.15	474690.2	1947437.8	OFAV	OFAV	OANN					
4	16	4.16	474697.3	1947432.3	APAL							
4	17	4.17	474707.9	1947437.8	OANN							
4	18	4.18	474716.7	1947434.0	OFAV	OFAV	OFAV	OFAV	OFAV	OFAV		
4	19	4.19	474720.3	1947443.3	OFAV							
4	20	4.20	474737.9	1947459.9	APAL							
4	21	4.21	474753.9	1947467.2	OFAV	OANN	OFAV					
4	22	4.22	474753.9	1947474.6	APAL							
6	1	6.1	474755.7	1947467.2	APAL							
6	2	6.2	474753.9	1947482.0	APAL							
6	3	6.3	474764.5	1947474.6	APAL							
6	4	6.4	474766.3	1947491.2	APAL							
6	5	6.5	474771.6	1947500.3	APAL							

POINT ID			UTM20N		Species and photos							
Survey	Point	Point ID	mE	mN	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
6	6	6.6	474784.0	1947498.6	APAL							
6	7	6.7	474785.7	1947483.7	APAL							
6	8	6.8	474785.7	1947472.7	APAL							
6	9	6.9	474798.1	1947463.5	APAL							
6	10	6.10	474815.8	1947461.6	APAL							
6	11	6.11	474828.1	1947456.0	APAL							
6	12	6.12	474833.4	1947457.9	APAL							
6	13	6.13	474838.7	1947454.2	APAL							
6	14	6.14	474840.5	1947450.5	APAL							
6	15	6.15	474842.3	1947444.9	APAL							
6	16	6.16	474858.2	1947456.0	APAL							
6	17	6.17	474859.9	1947463.4	APAL							
6	18	6.18	474872.4	1947472.6	APAL							
6	19	6.19	474863.6	1947481.9	APAL							
6	20	6.20	474875.9	1947483.6	APAL							
6	21	6.21	474886.5	1947474.4	APAL							
6	22	6.22	474890.1	1947474.4	APAL							
6	23	6.23	474893.6	1947472.5	APAL							
6	24	6.24	474890.1	1947470.8	APAL							
6	25	6.25	474890.1	1947463.4	APAL							
6	26	6.26	474890.0	1947444.9	APAL							
6	27	6.27	474889.8	1947435.7	APAL							
6	28	6.28	474879.4	1947437.6	APAL							
6	29	6.29	474874.1	1947430.2	APAL							
6	30	6.30	474870.5	1947426.5	APAL							
6	31	6.31	474870.5	1947417.2	APAL							
6	32	6.32	474870.5	1947413.6	APAL							
6	33	6.33	474859.9	1947415.5	APAL							
6	34	6.34	474859.9	1947417.3	APAL							
7	1	7.1	474193.5	1947424.0	OFAV							
7	2	7.2	474192.5	1947426.2	OFAV							
7	3	7.3	474193.9	1947417.3	OFAV							
7	4	7.4	474193.9	1947421.4	OFAV							
7	5	7.5	474192.0	1947422.0	DCYL	OFAV						
7	6	7.6	474203.0	1947416.6	OFAV							
7	7	7.7	474202.8	1947404.0	OFAV							
7	8	7.8	474218.4	1947396.6	OFAV							
7	9	7.9	474218.9	1947386.8	OFAV							

POINT ID			UTM20N		Species and photos							
Survey	Point	Point ID	mE	mN	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
7	10	7.10	474232.1	1947399.1	DCYL							
7	11	7.11	474235.3	1947401.8	DCYL							
7	12	7.12	474241.7	1947407.5	OFAV							
7	13	7.13	474247.8	1947393.9	OFAV							
7	14	7.14	474247.8	1947388.5	APAL							
7	15	7.15	474247.6	1947394.7	DCYL							
7	16	7.16	474248.1	1947390.8	OFAV							
7	17	7.17	474249.0	1947386.5	OANN							
7	18	7.18	474245.9	1947390.8	APAL							
7	19	7.19	474242.8	1947383.7	DCYL							
7	20	7.20	474244.5	1947375.2	OFAV							
7	21	7.21	474249.2	1947372.9	DCYL							
7	22	7.22	474246.4	1947370.1	DCYL							
7	23	7.23	474248.8	1947370.9	DCYL							
7	24	7.24	474251.6	1947369.0	OFAV							
7	25	7.25	474248.8	1947372.7	OFAV							
7	26	7.26	474256.3	1947376.2	DCYL							
7	27	7.27	474262.2	1947381.6	OFAV							
7	28	7.28	474273.9	1947374.8	APAL	OFAV						
7	29	7.29	474285.7	1947372.7	APAL	OFAV						
7	30	7.30	474295.1	1947384.1	APAL							
8	1	8.1	474919.9	1947341.6	OFAV							
8	2	8.2	474911.1	1947338.0	OFAV	OFAV	OFAV	OFAV				
8	3	8.3	474905.8	1947341.6	OFAV							
8	4	8.4	474902.2	1947349.1	OFAV							
8	5	8.5	474891.6	1947341.7	OFAV	DCYL	OFAV					
8	6	8.6	474896.9	1947332.5	OFAV	OFAV	OFAV	OFAV				
8	7	8.7	474891.6	1947334.2	DCYL							
8	8	8.8	474870.4	1947327.0	OFAV	OFAV						
8	9	8.9	474863.4	1947308.5	OFAV	OFAV	OFAV	OANN				
8	10	8.10	474858.0	1947297.4	OANN	OFAV	OFAV	OFAV	OFAV	OFAV		
8	11	8.11	474842.1	1947317.7	OFAV	OFAV	OFAV	OFAV	OFAV			
8	12	8.12	474861.6	1947334.3	OFAV							
8	13	8.13	474852.8	1947339.8	OFAV							
8	14	8.14	474843.9	1947330.6	OFAV	OFAV	OFAV	OFAV	OFAV			
8	15	8.15	474836.9	1947327.0	OFAV	OFAV						
8	16	8.16	474831.6	1947332.5	OFAV							
8	17	8.17	474836.9	1947338.1	OFAV	OFAV	OFAV	OFAV	OFAV	OFAV	OFAV	

POINT ID			UTM20N		Species and photos							
Survey	Point	Point ID	mE	mN	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
8	18	8.18	474836.9	1947343.6	OFAV	OFAV	DCYL					
8	19	8.19	474840.4	1947345.4	OFAV							
8	20	8.20	474826.3	1947352.8	OFAV							
8	21	8.21	474822.7	1947356.5	OFAV	OFAV	OFAV	OFAV	OFAV	OFAV		
8	22	8.22	474819.2	1947349.2	OFAV							
8	23	8.23	474813.9	1947347.3	OFAV							
8	24	8.24	474808.6	1947369.4	OFAV	OFAV	OFAV	OFAV	OFAV			
8	25	8.25	474805.1	1947375.0	OFAV							
8	26	8.26	474799.8	1947380.5	OFAV							
8	27	8.27	474775.0	1947378.6	OFAV							
8	28	8.28	474746.7	1947371.4	OFAV							
8	29	8.29	474744.9	1947376.9	OFAV	OFAV	OFAV	OFAV	OFAV	OFAV		
8	30	8.30	474741.5	1947391.6	APAL							
8	31	8.31	474766.2	1947408.2	OFAV	OFAV	OFAV					
8	32	8.32	474759.1	1947456.1	APAL							
8	33	8.33	474752.2	1947476.5	APAL							
8	34	8.34	474755.7	1947465.4	APAL							
8	35	8.35	474761.0	1947469.0	APAL							
8	36	8.36	474727.4	1947496.7	APAL							
8	37	8.37	474709.8	1947502.3	APAL							
8	38	8.38	474693.8	1947502.3	APAL							
8	39	8.39	474679.6	1947509.7	OFAV	OFAV	APAL					
9	1	9.1	474646.1	1947500.5	APAL							
9	2	9.2	474607.0	1947402.9	OFAV	OFAV	OFAV	OFAV	OFAV			
9	3	9.3	474599.9	1947410.3	OFAV							
9	4	9.4	474603.6	1947419.5	OFAV							
9	5	9.5	474594.7	1947419.5	OANN							
9	6	9.6	474598.3	1947425.0	OFAV	OFAV	OFAV					
9	7	9.7	474610.6	1947428.6	OFAV							
9	8	9.8	474591.2	1947434.2	APAL	OANN	OFAV					
9	9	9.9	474591.2	1947439.7	OFAV	OFAV						
9	10	9.10	474580.6	1947430.5	APAL	OFAV	OFAV	OFAV				
9	11	9.11	474573.4	1947423.1	OFAV	OFAV	APAL					
9	12	9.12	474562.8	1947419.5	OFAV							
9	13	9.13	474573.4	1947410.3	OFAV	OFAV	OFAV	OFAV	OANN			
9	14	9.14	474569.9	1947401.0	OFAV							
9	15	9.15	474557.5	1947415.9	OFAV	OFAV	OFAV	OFAV	OFAV			
9	16	9.16	474557.5	1947423.2	OFAV	OFAV	OANN					

POINT ID			UTM20N		Species and photos							
Survey	Point	Point ID	mE	mN	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
9	17	9.17	474554.0	1947426.9	OFAV	OFAV						
9	18	9.18	474550.5	1947415.9	APAL	OFAV	OFAV					
9	19	9.19	474550.5	1947410.3	OFAV							
9	20	9.20	474541.6	1947415.9	APAL							
9	21	9.21	474545.2	1947423.2	OFAV	OFAV	OFAV					
9	22	9.22	474541.6	1947425.1	OANN	OANN						
9	23	9.23	474541.6	1947443.5	APAL							
9	24	9.24	474539.9	1947439.8	OFAV							
9	25	9.25	474532.8	1947425.1	OFAV	OFAV	OFAV					
9	26	9.26	474529.3	1947421.4	OFAV	OFAV						
9	27	9.27	474525.7	1947415.9	APAL							
9	28	9.28	474524.0	1947425.1	OFAV							
9	29	9.29	474518.7	1947434.3	APAL	OFAV	OFAV	OFAV				
9	30	9.30	474518.7	1947436.2	OFAV							
9	31	9.31	474508.1	1947443.6	APAL	OFAV						
9	32	9.32	474493.9	1947412.2	APAL							
9	33	9.33	474499.2	1947408.5	OFAV	APAL	OFAV					
9	34	9.34	474486.9	1947412.2	OFAV							
9	35	9.35	474486.8	1947404.9	APAL	OFAV	OFAV	APAL	OFAV			
9	36	9.36	474474.4	1947408.6	APAL							
9	37	9.37	474469.1	1947412.2	OFAV							
9	38	9.38	474456.7	1947406.7	OFAV							
9	39	9.39	474467.3	1947421.5	APAL	APAL						
9	40	9.40	474453.2	1947425.2	OANN							
9	41	9.41	474451.4	1947390.1	APAL							

2c: Literature survey, D. Hassell

Black Rocks Area Overview

By: [redacted], Lunulata Marine Consultancy

For: [redacted], EcoVision

4 February 2020

Summary

This overview will focus specifically on the quality of the marine and terrestrial ecosystem of the geographical area surrounding the Black Rocks. The Black Rocks area is designated within a larger area known as Giles Quarter, and contains a part of Great Level Bay. It is in the Multipurpose zone in the Saba National Marine Park which allows different recreational uses such as fishing and diving.

Giles Quarter Shallow dive site is a true biogenic reef (van't Hof, 1991; Bak 1977), made of pure limestone, made up of various flora and fauna such as the endangered species *Acropora palmata*, Elkhorn coral. This area contains diffused/dense patch reef, seagrass, algal fields and is 5% live coral with 25% macroalgae coverage scoring it as Fair under the Reef Health Index (van der Vlugt, 2016). Giles Quarter has reported sightings of keystone conservation species such as *Megaptera novaeangliae*, Humpback whales (SCF, 2020; Debrot et al., 2013).

The terrestrial vegetation is predominately *Aristida – Mitracarpus* and *Botriochloa pertusa* recognized by Croton Thickets, which is considered a dry woodland (Freitas et al., 2016). Freitas et al, (2016) described Giles Quarter with poor soil formation. Boeken & Leopold (2019) described the population census of 16-34 Red-Billed Tropics birds in this area which is considered an Important Breeding Area. Within a specific study, Tieskens et al (2014), the Black Rocks area was included in a value mapping of the terrestrial and marine ecosystems of Saba. The terrestrial area was valued low carbon sequestration/ economic value however the marine economic value was high (180,000 USD) based on the significant present coral reef.

General Description

Saba formed about 500,000 years ago as a result of volcanic activity (Westermann and Kiel, 1961). The peak of the volcano is at 877 meters, and the Black Rocks is found along the coastline of Saba. Black Rocks area location is south-east of the Fort Bay harbor. This location is currently not part of the terrestrial national park. The land has no urban civilization, but it is a critical habitat area for flora and fauna; marine and terrestrial. This overview focuses on the area of the Black Rocks which is encompassed in the sites Giles Quarter Shallow (marine) and Great Level Bay/Giles Quarter (terrestrial) and will be using these site names to refer to the Black Rocks.

The dive site, Giles Quarter Shallow, is within the Saba National Marine Park (further referred to as SNMP), which is managed by the Saba Conservation Foundation (SCF, 2020). The SNMP encircles the entire island from the high-water mark to a depth of 60 m, including the seabed and overlying waters. A zoning plan divides the park for various recreational and commercial uses, and in the Black Rocks area, the current zone is a Multipurpose zone (SCF, 2020). The multipurpose zone consists of fishing, diving, and other boat traffic activities.

The Great Level Bay site is part of an Important Breeding Area for critical species such as the Red-Billed Tropic bird. Giles Quarter terrestrial area is one of the four vegetation zones found on Saba and is described as by grassy meadows with scattered shrubs (SCF, 2020).

Marine Value of the Area

In the Caribbean, there is one standardized research method to understand the status and trends of the reefs—Global Coral Reef Monitoring Network method (GCRMN, 2020). This method ensures all assessments of the reefs are comparable by creating multi-annual datasets (Jackson et al, 2012). These assessments provide annual information on the fish biomass, macroalgae cover, coral disease, and critical invertebrates resulting in the overall status of the reef (Jackson et al, 2014). For every dive site, a Reef Health Index defines the health of the reef by the use of indicators (Figure 1; Healthy Reefs Initiative, 2015). Overall, according to this study (Menger, 2016), scores are given for all sites sampled (Table 1), including Giles Quarter Shallow. Over the years, Saba has faced a downward trend in its live coral coverage, which has led to increases in algae and overall a decrease in the live coral coverage.

Reef Health Index (RHI)

Reef Health Index Indicators	Very Good (5)	Good (4)	Fair (3)	Poor (2)	Critical (1)
Coral Cover (%)	≥40	20.0-39.9	10.0-19.9	5.0-9.9	<5
Fleshy Macroalgal Cover (%)	0-0.9	1.0-5.0	5.1-12.0	12.1-25	>25.0
Key Herbivorous Fish (g/100m^2) *(only parrotfish and surgeonfish)*	≥3480	2880-3479	1920-2879	960-1919	<960

Figure 1 Reef Health Index based on various indicators (Healthy Reefs Initiative, 2015)

Giles Quarter boasts a different reef complex, namely known as a true biogenic reef (ref), which is a reef habitat formed on limestone (Van't Hof, 1991 & Bak 1977). The SNMP is home to various flora and fauna listed in the SPAW Protocol, which receives international protection (Appendix 1).

Status of the Coral Reef

The latest and most complete survey in 2016 (van der Vlugt) gives a clear overview of Giles Quarter Shallow. Based on this study, the author described the current benthic status per site categorized it by fished or unfished zones. Based on Meesters et al, (in prep) study the zonation was identified by bare rock, bare sand, diffuse/dense patch reef, coral reef, algal and seagrass fields (Figure 2). The current status of benthic cover reviewed in this study (van der Vlugt, 2016) presents itself as a limitation. However, according to study's results, the Cover % results for Giles Quarter Shallow are as follows:

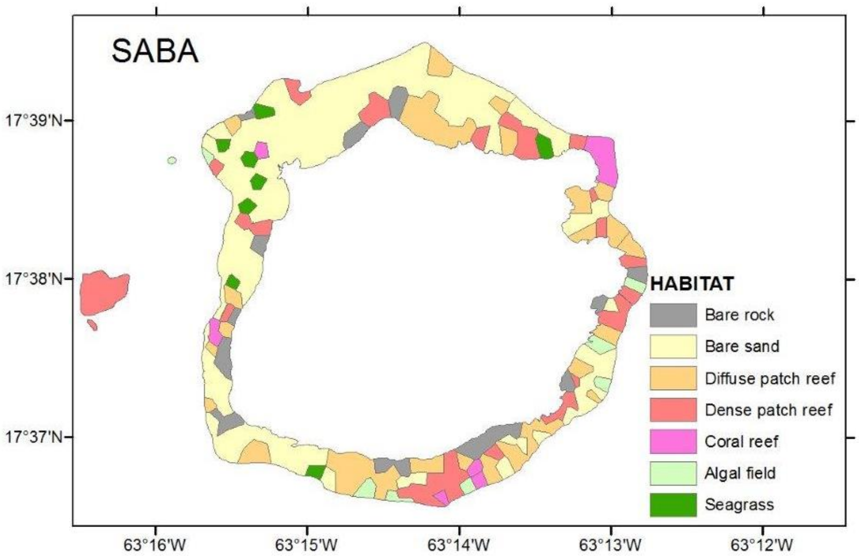


Figure 2 Marine Zonation (Meesters et al, in prep)

Cyanobacteria: 8%
Macroalgae: 25%
Coral: 3%
Gorgonian: 1.5%

The current status of coral cover has been scored by its Reef Health Index (RHI) which has included macroalgae heights, density of coral recruits (#/100m^2), horizontal transparency, density of key invertebrates (sea urchins and cucumbers (#/100m^2)). These are the following results for Giles Quarter Shallow:

Coral Cover: 2 | RHI 1

Macroalgae Cover:	23.1 | RHI 2
Average Macroalgae Height:	4.5 cm
Density of Coral Recruits:	5.5/ 100 m^2
Horizontal Transparency:	24m
Density of Key Invertebrates:	0/100 m^2

The overview of found hard coral species in the SNMP that were described by van der Vlugt (2016) can be found in Appendix 1.

Important Coral Species (IUCN) present in the area

This area is known to contain essential coral species such as the *Acropora palmata*, Elkhorn coral, currently listed under the IUCN list as Critically Endangered (Appendix 2). On Saba, this threatened species is still found in different locations around the island such as Giles Quarter Shallow. Erosion is a contributing factor to the demise of this species. One of the studies that focused on this species and its relationship with erosion (Mulder, 2017) identified potential challenges regarding sedimentation on endangered coral species especially Giles Quarter which has been marked with high erosion intensity (Mulder, 2017). During rainy seasons when there is an extreme land runoff, there can be increased turbidity in the sea, which leads to smothering the exposed coral tissue. Unfortunately, the coral tissue can be killed within a few days (Riefel & Branch, 1995 & Golbuu, Victor, Wolanski & Richmond, 2003).

This Elkhorn coral is specifically vulnerable to sedimentation particles and requires the assistance of wave action to survive, and can be an indication why it exists in specific locations around Saba such as Giles Quarter Shallow. Results from this study (Mulder, 2017) demonstrated that for Elkhorn to grow, the wave action was not the determining factor, instead, it's the combination with erosion intensity.

Diversity of Fish species

As mentioned previously, the marine park has established this area as a multipurpose zone, which includes recreational fishing. However, no anchoring or mooring is allowed in this area (SCF, 2020). Menger 2016 described an overview of the fish diversity using the GCRMN method. The diversity of fish categories in this method was herbivorous and commercial, and categories such as Fished/Not Fished areas (Polunin & Roberts, 1993). Based on van der Vlugt study (2016), the total fish density was much higher in unfished zones rather than fished zones. In this case, since Black Rocks are apart of a fished zone, it is difficult to distinguish whether there is a significant difference compared to other sites since it is a knowledge gap at the moment.

Giles Quarter Shallowed resulted in 2,840 of Key Herbivorous fish (g/100 m^2) and ranked as Fair on the Reef Health Index. The Key Commercial Fish scored 580 (#/100m^2), and ranked Poor for RHI. Overall, the mean RHI for this area scored 2.5, which is considered Fair.

Marine Mammals

The Saba National Marine Park classifies as part of the Yarari Marine Mammal and Shark Sanctuary, established officially on 2 September 2015 serving as a sanctuary for critical activities of the marine mammals (feeding, calving, mating) (Debrot et al, 2017). Giles Quarter has reported marine mammal sightings such as *Megaptera novaeangliae,* Humpback whales based on local fishermen reportings. Within the Dutch Caribbean waters, the latest study demonstrated 84 marine mammal records

(Debrot et al., 2017). Giles Quarter Shallow is an important for these keystone conservation species as fauna may use it for various life history strategies such as mating.

Terrestrial Value of the Area

In September 2017, Saba faced two category five hurricanes; Irma and Maria. These natural disturbances had a significant impact on the ecosystems. The GCRMN assessments have not provided the results after these hurricanes as yet.

Habitat Classification

The classification of Giles Quarter is a tropical savannah climate with a pronounced dry season, with the driest month having precipitation less than 60 mm (Freitas et al, 2016). The geological area is dominated by agglomerates and tuffs is evident of Saba's volcanic activity as it is former lava flows. Gile's Quarters' "cherty sandy loam" soil layer forms the dryer and have shallow topsoils over stony parent material that is susceptible to sheet erosion.

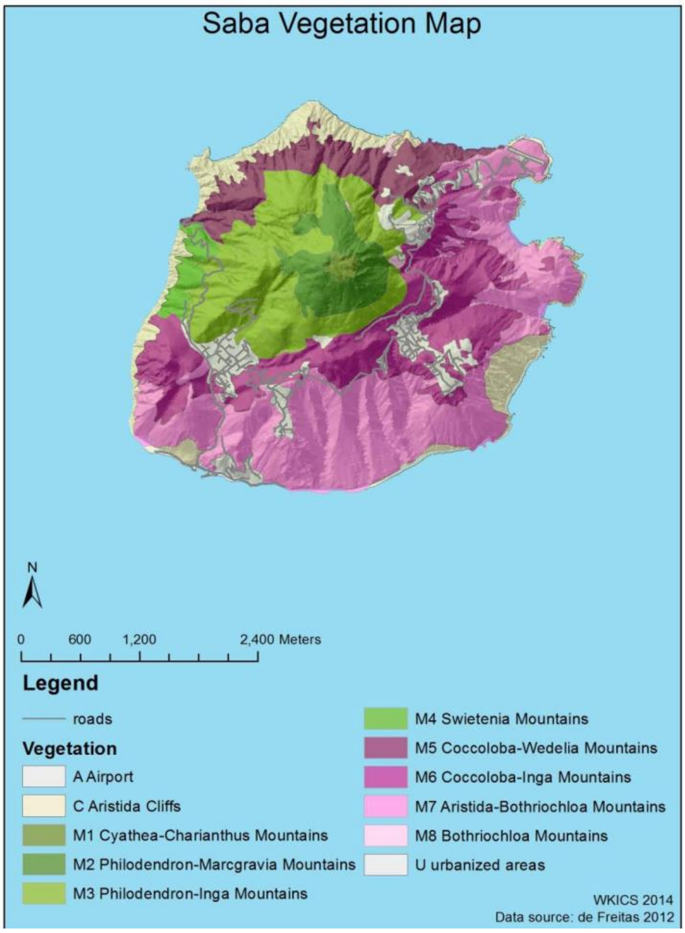


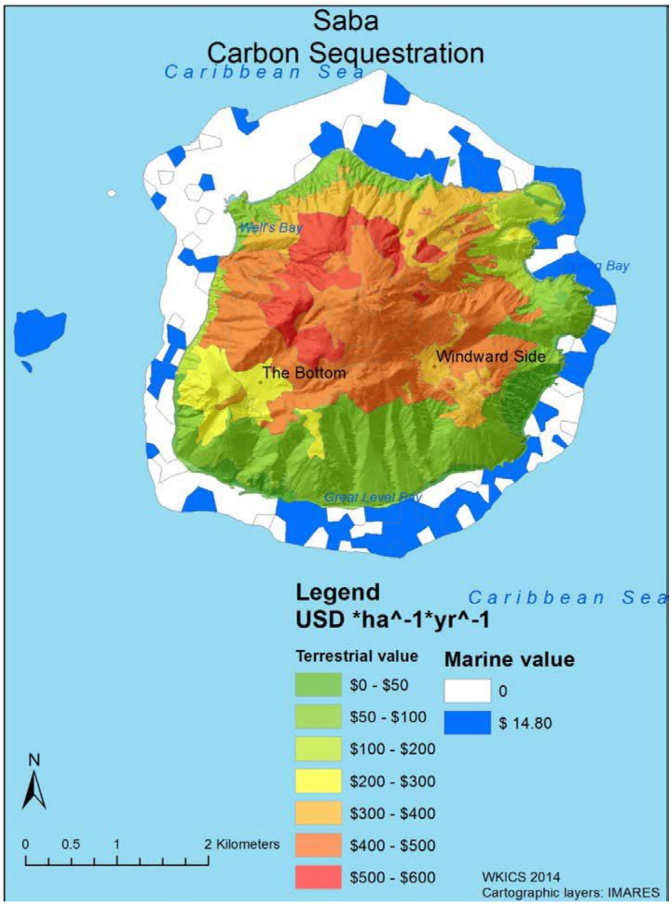
Figure 3 Vegetation map Saba (De Freitas, 2012; Tieskens e al, 2014)

Based on the Freitas et al., (2016) study, this area's landscape vegetation, *Aristida-Bothriochloa* vegetation dominates this area (Figure 3, Saba Vegetation Map). It occurs on the lowest slopes of Saba. The primary vegetation type is *Aristida – Mitracarpus*, with lesser roles for the *Bothriochloa pertusa* and *Wedelia Plumbago.* The *Bothriochloa* and *Aristida – Mitracarpus* is a dry evergreen forest/ bushland with Croton thickets. The *Wedelia – Plumbago* is a woodland derived from the seasonal forest. The lower inclination of the slopes and the presence of the grazers explains this type of dry woodland forest. These vegetation areas also demonstrated the presence of goats. According to Freitas et al. (2016), soil formation is extremely poor in this area.

Value of Carbon Sequestration for Marine and Terrestrial areas of Saba

Greenhouse gases that are released into the atmosphere contribute to climate change, and carbon sequestration is buffered by ecosystems such as coral reefs and forests. On Saba, 1,3000 hectares are dry forests providing carbon sequestration that is estimated at 27 thousand tons per year (Tieskens et al.,2014; van der Lely et al, 2014). This same study has proposed that the coral reef's carbon sequestration is estimated at 27 thousand tons per year.

The authors, Tieskens et al (2014) focused the study on the tourism, cultural, and recreational values resulting in total economic value for terrestrial and marine ecosystems of Saba. The study focused on value mapping of nature Saba by calculating a total economic value, it characterizes the value of the Black Rocks area (Great Level Bay) to be 180,000 USD based on quality of the reef. Due to the most unique features of Saba being present above the 550 meters range, the total economic value of the Giles Quarter/Great Level Bay area is low (Tieskens et al.,2014).



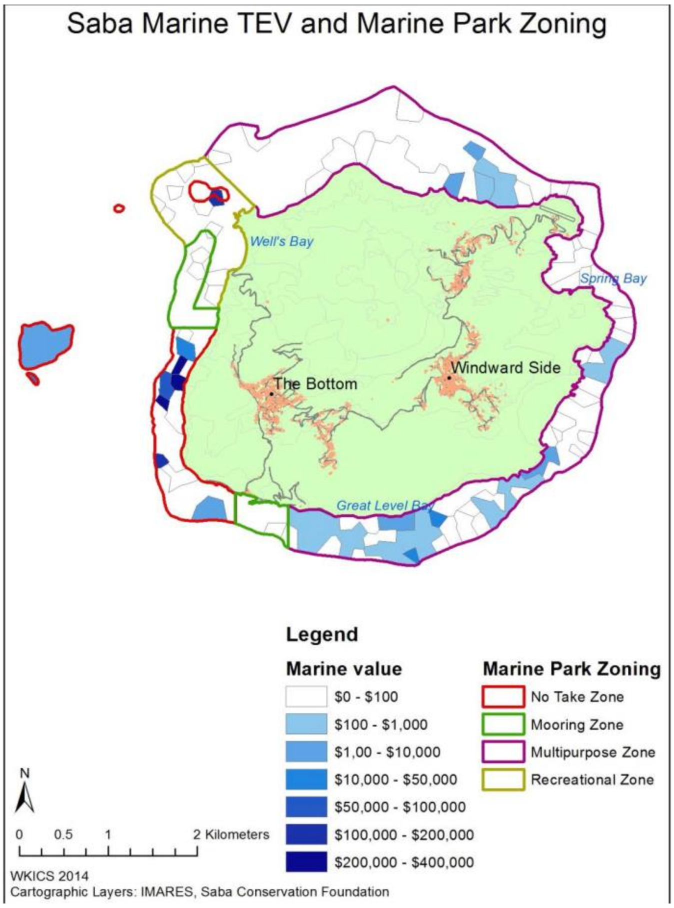


Figure 4 Left: Carbon Sequestration Allocation within the terrestrial and marine ecosystems of Saba | Right: Total Economic Value of the zonation within the Saba National Marine Park (Tieskens et al, 2014)

Important Birds of the Area

As fish cannot see the zones in a marine park, birds behave the same. Therefore, to isolate the birds in the Black Rocks area is difficult, but fortunately, Saba's coastline is relatively similar surrounding the island. Since the Black Rocks area is considered part of the Great Level Bay (Figure 4, observation.org); thus, this sampled area will be the reference for the Black Rocks.

Figure 5Adult Red-billed tropicbird in nesting habitat with chick at Great Level (Boeken, 2011)

Geelhoed et al. (2013) and SCF (2020) identified an important bird area, which is Saba’s coastline (AN 006). Saba’s coastline includes all areas from the waterline to 400 meters inland around Saba. Part of BirdLIfe International, this Important Bird Area program recognizes sites that only meet the criteria, for instance, if the site is known to have globally threatened species. The site description will constitute the following (Geelhoed et al, 2013).

Location, boundaries, and size

Described by IUCN Habitat, it is considered a rocky area (e.g., inland cliffs, mountain peaks). The boundaries excluded are the inhabited area around Fort bay and the area around the airport. The Black Rocks are not considered a core area in the IBA (which is currently the Sulphur Mine and Green Island) (Geelhoed et al., 2013).

Bird Species

Brown et al (2009) has reported 87 species for the island, and according to Avibase there are 114 species; however, the focus for this overview will be the seabirds. The IBA is significant for all sea birds, especially the Red-Bill Tropicbird and Audubon's Shearwater. Specifically, the local population of the Red-Bill Tropicbird contributes to 1% of the global estimated population giving it a principal ecological value for Saba. These nests are present around the entire perimeter of the island in coastal cliffs and rocky hills. The typical breeding sites are found in lower coastal elevations.

Boeken (2011) described the Great Level Bay (Figure 6) area with a maximum number of 42 adults, and 20 nests with a ratio of 2:4 (adult: nests), and estimated the colony size at 100. Boeken & Leopold (2019) has recorded the population census being 16-34 in this area. Present colonies in Great Level (near the Black Rocks area) have lost breeding pairs but are now producing chicks. The main colony appears stable but is suffering from predation from feral cats and rats. Recently, Boeken & Leopold (2019) recovered a ring from the oldest ever Red-Billed Tropicbird, aged 19 years three months, in the Great Level Bay area.

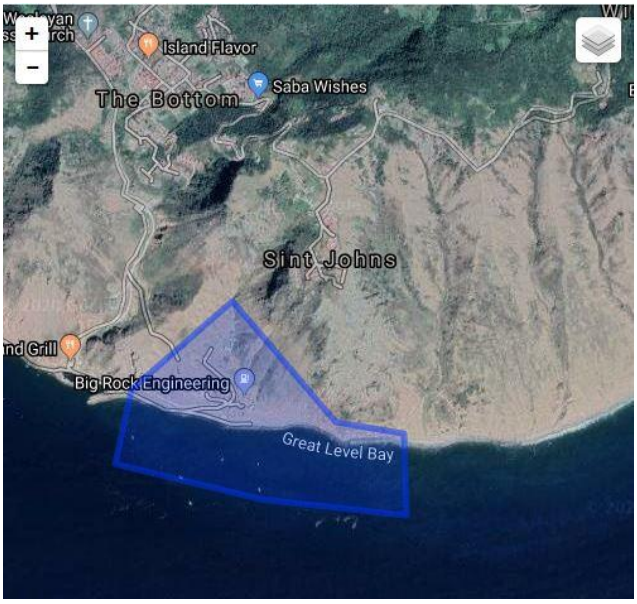


Figure 6 Location of the observed bird species within the Great Level Bay (Observation.org, 2020)

Other species that have been recorded and described in this area (Observation.org, 2017-2020) can be seen in Table 1.

Common Name	Scientific Name	Record	IUCN Status
American Osprey	*Pandion haliaetus carolinensis*	Observation.org, 2019	-
Magnificent Frigatebird	*Fregata magnificens*	Observation.org, 2019	Least Concern
Red-tailed Hawk	*Buteo jamaicensis*	Observation.org, 2019	Least Concern
Red Billed Tropicbird	*Phaethon aethereus*	Observation.org, 2018	Least Concern- Population Decreasing
Zenaida Dove	*Zenaida aurita*	Observation.org, 2018	Least Concern
American Kestrel	*Flaco spaeverius caribaearm*	Observation.org, 2018	Least Concern
Brown Booby	*Sula leucogaster*	Observation.org, 2018	Least Concern
House Sparrow	*Passer domesticus*	Observation.org, 2018	Least Concern

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Appendices

Appendix 1

Overview of Found Hard Coral Species in the SNMP (van der Vlugt, 2016)

Species	***%***
Acropora palmata	1.57
Agaricia agaricites	3.50
Agaricia fragilis	0.35
Agaricia lamarcki	0.25
Agaricia tenuifolia	0.26
Coral (general)	1.53
Dichocoenia stellaris	0.10
Dichocoenia stokesi	0.05
Diploria clivosa	0.31
Diploria labyrinthiformis	1.66
Diploria strigosa	8.89
Madracis decactis	0.05
Meandrina meandrites	1.32
Millipora alcicornis	3.29
Millipora complanata	8.45
Montastraea annularis	0.56
Montastraea cavernosa	6.62
Montastrea faveolata	20.24
Mycetophyllia aliciae	0.10
Mycetophyllia lamarckiana	0.10
Porites astreoides	21.52
Porites divaricata	0.97
Porites porites	5.34
Siderastrea radians	0.67
Siderastrea siderea	8.82
Solenastrea bournoni	3.42
Solenastrea hyades	0.05

Appendix 2

List of animal species within the site that are in the IUCN Red List. IUCN Red List (CR: critically endangered; EN: endangered; VU: vulnerable)

List of species in IUCN red list that are present in SNMP site	IUCN Status	Estimate of population size	Comments if any
Elkhorn coral: Acropora palmata	CR - Critically endangered	not given	
Staghorn coral: Acropora cervicornis	CR - Critically endangered	not given	
Warsaw grouper: Hyporthodus nigritus	CR - Critically endangered	not given	
Hawksbill turtle: Eretmochelys imbricata	CR - Critically endangered	not given	
Leatherback turtle: Dermochelys coriacea	CR - Critically endangered	not given	
Black-capped Petrel: Pterodroma hasitata	EN - Endangered	not given	
Mountainous Star Coral: Montastrea annularis	EN - Endangered	not given	
Boulder star coral: Montastrea faveolata	EN - Endangered	not given	
Bladed Box Fire Coral: Millepora striata	EN - Endangered	not given	
Nassau Grouper: Epinephelus striatus	EN - Endangered	not given	
Barndoor Skate: Dipturus laevis	EN - Endangered	not given	
Winter Skate: Leucoraja ocellata	EN - Endangered	not given	
Fin Whale: Balaenoptera physalis	EN - Endangered	not given	
Coalfish Whale: Balaenoptera borealis	EN - Endangered	not given	
Blue Whale: Balaenoptera musculus	EN - Endangered	not given	
North Atlantic Right Whale: Eubalaena glacialis	EN - Endangered	not given	
Green Turtle: Chelonia mydas	EN - Endangered	not given	
Leaf Coral: Agaricia lamarcki	VU - Vulnerable	not given	
Pillar Coral: Dendrogyra cylindrus	VU - Vulnerable	not given	
Elliptical Star Coral: Dichocoenia stokesii	VU - Vulnerable	not given	
Rough cactus coral: Mycetophyllia ferox	VU - Vulnerable	not given	
Bumpy Star Coral: Montastrea franksi	VU - Vulnerable	not given	
Lined Seahorse: Hippocampus erectus	VU - Vulnerable	not given	

Yellowfin Grouper: Epinephelus flavolimbatus	VU - Vulnerable	not given	
Masked Hamlet: Hypoplectrus providencianus	VU - Vulnerable	not given	
Poey's Grouper, Grouper, White Grouper: Hyporthodus flavolimbatus	VU - Vulnerable	not given	
Seabass, Snowy Grouper, Spotted Grouper: Hyporthodus niveatus	VU - Vulnerable	not given	
Hogfish: Lachnolaimus maximus	VU - Vulnerable	not given	
Cubera Snapper: Lujanus cyanopterus	VU - Vulnerable	not given	
Mutton Snapper: Lutjanus analis	VU - Vulnerable	not given	
Yellowmouth Grouper: Mycteroperca interstitialis	VU - Vulnerable	not given	
Bigeye Tuna: Thunnus obesus	VU - Vulnerable	not given	
Queen Triggerfish: Balistes vetula	VU - Vulnerable	not given	
Marble Grouper: Dermatolepis inermis	VU - Vulnerable	not given	
Giant Manta Ray: Manta birostris	VU - Vulnerable	not given	
Grey Nurse Shark: Carcharias taurus	VU - Vulnerable	not given	
Small-tooth Sand Tiger Shark, : Odontaspis ferox	VU - Vulnerable	not given	
Bigeye Thresher Shark: Alopias superciliosus	VU - Vulnerable	not given	
Dusky Shark: Carcharhinus obscurus	VU - Vulnerable	not given	
Sandbar Shark: Carcharhinus plumbeus	VU - Vulnerable	not given	
Night Shark: Carcharhinus signatus	VU - Vulnerable	not given	
Gulper Shark: Centrophorus granulosus	VU - Vulnerable	not given	
Longfin Mako: Isurus paucus	VU - Vulnerable	not given	
Whale Shark: Rhincodon typus	VU - Vulnerable	not given	
Great White Shark: Carcharodon carcharias	VU - Vulnerable	not given	
Clubnose Guitarfish: Glaucostegus thouin	VU - Vulnerable	not given	
Butterfly ray: Gymnura altavela	VU - Vulnerable	not given	
Great Sperm Whale: Physeter catodon	VU - Vulnerable	not given	
Sperm Whale: Physeter macrocephalus	VU - Vulnerable	not given	
Humpback Whale: Megaptera novaeangliae	VU - Vulnerable	not given	

2d: Relative cover patch reef (summary)

Annex 2d: Relative cover at patch reef (summary)

Benthic cover (%)	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 7	Transect 8	Transect 9	Transect 10	Overall average
CORAL (HCO)	1.2%	2.6%	3.8%	5.3%	3.0%	1.7%	4.3%	4.5%	3.1%	2.1%	3.2%
CRUSTOSE CORALLINE ALGAE (CCA)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CYANOBACTERIA (CYAN)	1.8%	1.1%	1.6%	1.0%	1.9%	0.5%	0.3%	0.3%	1.0%	0.6%	1.0%
HYDROZOA (HYD)	0.1%	0.1%	0.2%	0.2%	0.2%	0.4%	0.1%	0.4%	0.1%	0.3%	0.2%
MACROALGAE (MACR)	29.7%	37.1%	32.6%	34.4%	30.1%	20.9%	23.6%	25.3%	22.3%	3.6%	25.9%
SAND (SAND)	45.6%	39.0%	49.5%	45.2%	52.6%	52.5%	51.4%	48.9%	60.5%	83.4%	52.8%
SOFT CORALS (SCO)	2.1%	2.9%	1.5%	2.8%	1.2%	2.0%	1.5%	1.5%	0.3%	0.0%	1.6%
SPONGES (SPON)	6.5%	3.6%	1.8%	3.2%	2.7%	6.8%	6.4%	3.4%	1.9%	0.1%	3.6%
SUBSTRATE (DEAD) (SUBS)	4.1%	2.8%	1.8%	3.0%	2.1%	1.1%	0.4%	2.6%	1.8%	2.5%	2.2%
TUNICATES (TUN)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
TURF (TURF)	8.0%	9.3%	7.1%	4.8%	6.0%	13.8%	12.1%	12.5%	9.0%	7.3%	9.0%
UNINDENTIFIED (TO SPECIES LEVEL) (UNI)	0.1%	0.1%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
UNKNOWN (UNKN)	0.9%	1.4%	0.1%	0.3%	0.1%	0.3%	0.0%	0.8%	0.1%	0.0%	0.4%
BRANCHING CORALLINE ALGAE (BCA)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
TAPE, WAND, SHADOW (TWS)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

List of coral species identified
Agaricia agaricites (AAGA)
Agaricia humilis (AHUM)
Dendrogyra cylindrus (DCYL)
Dichocoenia stokesi (DSTO)
Diploria labyrinthiformis (DLAB)
Eusmilia fastigiata (EFAS)
Favia fragum (FFAV)
Madracis decactis (MDEC)
Madracis decactis (MPHA)
Madracis mirabilis (MMIR)
Madracis pharensis (MPHA)

Madracis senaria (MSEN)
Meandrina meandrites (MMEA)
Montastraea cavernosa (MCAV)
Orbicella faveolata (OFAV)
Porites asteroides (PAST)
Porites furcata (PFUR)
Porites porites (PPOR)
Pseudodiploria clivosa (PCLI)
Pseudodiploria strigosa (PSTR)
Siderastrea radians (SRAD)
Siderastrea siderea (SSID)
Stephanocoenia intersepta (SINT)
23

2e: Coral relocation trial report, Ayumi Kuramae Izioka, Saba Conservation Foundation

Coral relocation trial - Progress report

[redacted]

Science coordinator

Saba Conservation Foundation

Fort Bay, Saba

Caribbean Netherlands

Table of Contents

1 When was it started?

All materials were bought and delivered to Saba Conservation Foundation at the beginning of December 2020. Preparations and building of the coral relocation tables started at the same time period.

In February, it took three days to get more materials to build the coral tables and 5 dives in total to get one suitable area equipped with all the relocation structures, collecting corals and placing them.

Scouting suitable areas to place the coral relocation tables and nursery trees were done for the first time on December 18, 2020 and the actual suitable areas were found on February 11, 2021 towards Hole in the Corner area (the most preferred area). The same day two relocation tables and 2 nursery trees were anchored, and corals were relocated from the harbor expansion area and from the nursery area on the trail tables.

At the end of February 2021 another two tables were built for the second relocation area (West side of the island). Gathering materials, assembling, finding a suitable area and deploying the tables with trees costs two full days of work.

2 Relocation sites

2.1 Hole in the corner

All fragments of the species *Acropora palmata* and Orbicella have been collected and transplanted on the same day (25th of February 2021) for Whole in the Corner area. The importance of collecting and transplanting on the same day is to prevent any further stress on the coral and to ensure the water temperature is the same. On the relocation day, the water temperature was 26 degrees Celsius.

Species	**Origin**	**Original water Temp.**	**Original depth**	**Transplant Temp**	**Transplant Depth**
A. *Palmata*	Black Rocks	26 C	5,5m	26 C	14.5 m
A. *cervicornis*	Coral nursery	26 C	12m	26 C	13 – 13.8 m
Orbicella	Black Rockss	26 C	11.6 – 12.5 m	26 C	14.5 m

Fragments of Orbicella were collected in 2 different methods: as whole colonies and colonies fragmented in 2 pieces. Fragmenting whole colonies will indicate if broken pieces during the actual full relocation will have an acceptable survival rate of 60-80%, since large fragments will have the risk of being broken during transport. Additionally, *Orbicella* species have shown to have a better survival rate when (micro)fragmented.

A. palmata fragments were collected from two different colonies in the wild from the same area as where the Black Rock harbor is planned to be built. Health and sturdiness between the different colonies can vary greatly.

A. cervicornis fragments were also collected on the same date from the coral nursery area and were transplanted to coral nursery trees in Whole in the Corner. There are no wild colonies of *A. cervicornis* on the South side of Saba, hence the use of the fragments from the coral nursery.

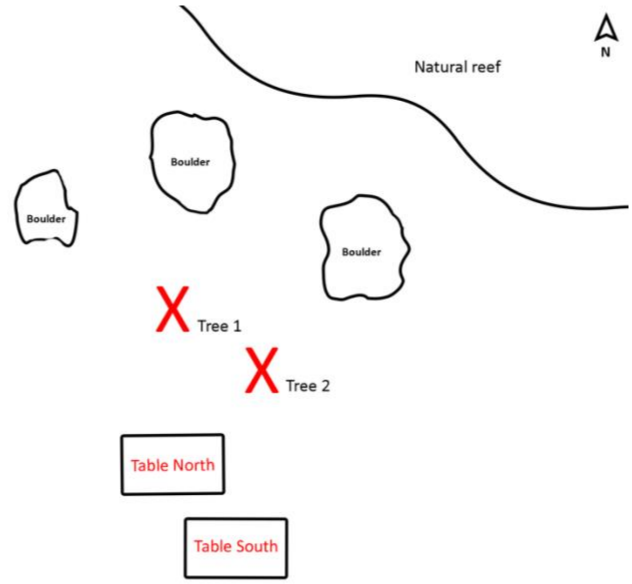


FIGURE 1. HOLE IN THE CORNER MAP

2.1.1 Tables

In order to prevent that the tables will have the same set-up; coral species were randomized. This prevents corals of the same species or the same colony to be placed on the same place on the two tables.

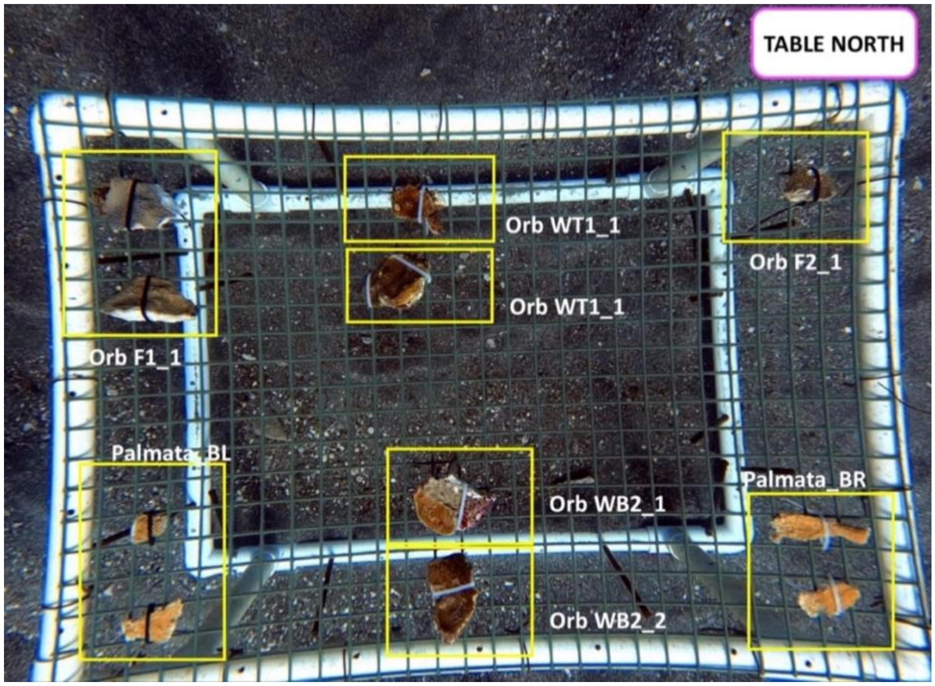


FIGURE 2. TABLE NORTH SET UP

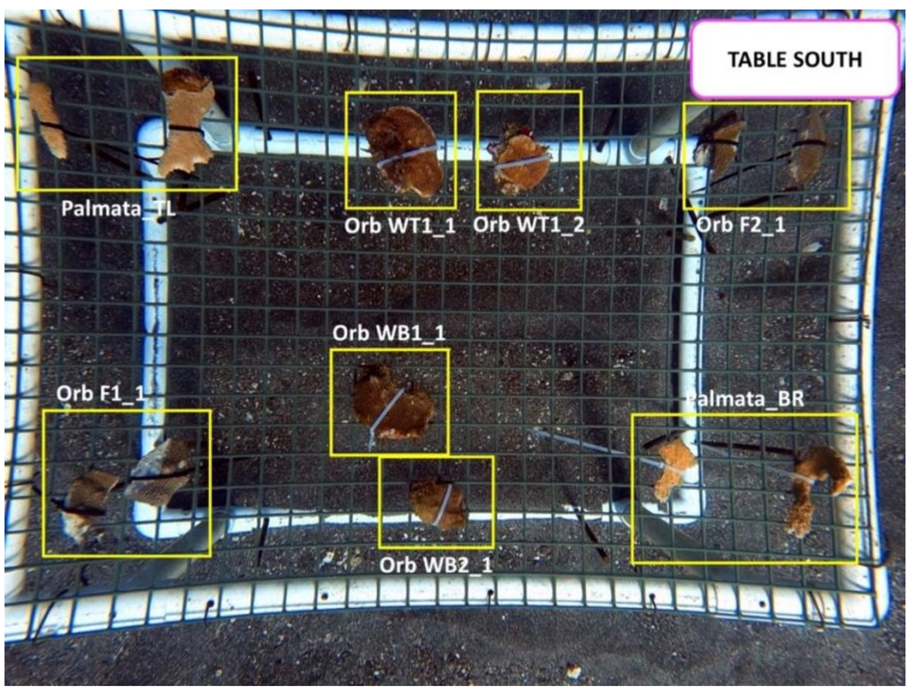


Figure 3. Table South Set up

TABLE NORTH					
Coding	**Description**	**Species**	**Relocation_Date**	**Health_Start**	**Health_Interim**
Orb **F**1_1	Orbicella Colony 1_fragment 1	*Orbicella spp.*	25-Feb-2021	100%	90% (March 12)
Orb **WT**1_1	Orbicella Whole Top 1_fragment 1	*Orbicella spp.*	25-Feb-2021	100%	90% (March 12)
Orb **WT**1_2	Orbicella Whole Top 1_fragment 2	*Orbicella spp.*	25-Feb-2021	100%	90% (March 12)
Orb **F**2_1	Orbicella Colony 2_fragment 1	*Orbicella spp.*	25-Feb-2021	100%	90% (March 12)
Palmata_BL	Palmata fragment_Bottom Left	*A. palmata.*	25-Feb-2021	100%	90% (March 12)
Orb **WB**2_1	Orbicella Whole Bottom 1_fragment 1	*Orbicella spp.*	25-Feb-2021	100%	90% (March 12)
Orb **WB**2_2	Orbicella Whole Bottom 1_fragment 2	*Orbicella spp.*	25-Feb-2021	100%	90% (March 12)
Palmata_BR	Palmata fragment_Bottom Right	*A. palmata*	25-Feb-2021	100%	90% (March 12)

TABLE SOUTH					
Coding	**Description**	**Species**	**Relocation_Date**	**Health_Start**	**Health_Interim**
Palmata_TL	Palmata fragment_Top left	*A. palmata*	25-Feb-2021	100%	90% (March, 12)
Orb **WT1**_1	Orbicella Whole Top colony 1_ fragment 1	*Orbicella spp.*	25-Feb-2021	100%	90% (March, 12)
Orb **WT**1_2	Orbicella Whole Top colony 1_fragment 2	*Orbicella spp.*	25-Feb-2021	100%	80% (March, 12)
Orb **F2**_1	Orbicella Fragmented 2_colony 1	*Orbicella spp.*	25-Feb-2021	100%	80% (March, 12)
Orb **F1**_1	Orbicella Fragmented 1_colony 1	*Orbicella spp.*	25-Feb-2021	100%	80% (March, 12)
Orb **WB**1_1	Orbicella Whole Bottom colon 1_ fragment 1	*Orbicella spp.*	25-Feb-2021	100%	80% (March, 12)
Orb WB2_1	Orbicella Whole Bottom colon 2_ fragment 1	*Orbicella spp.*	25-Feb-2021	100%	80% (March 12)
Palmata_BR	Palmata fragment Bottom Right	*A. palmata*	25-Feb-2021	100%	90% (March, 12)

NOTE: Final mortality rate discussed in chapter “Health status of corals”

2.1.2 Trees

The trees in hole in the corner were placed close to the tables as following:

To prevent that all fragments from the same colony were placed on the same depth, fragments were divided evenly between two trees where the first half is placed on top of tree 1 and the other half is placed on the bottom of tree 2.

The X-number of fragments were then randomly distributed between the tree branches to prevent that too many fragments are attached to only the top branches.

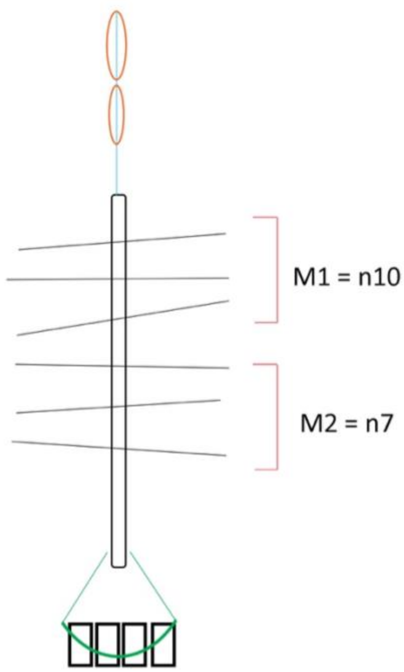


Figure 4. Tree 1

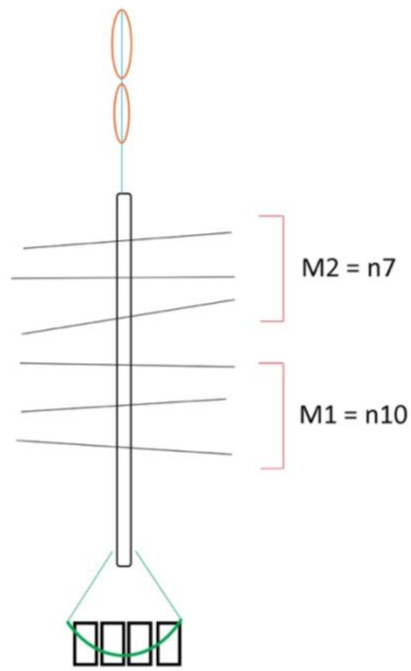


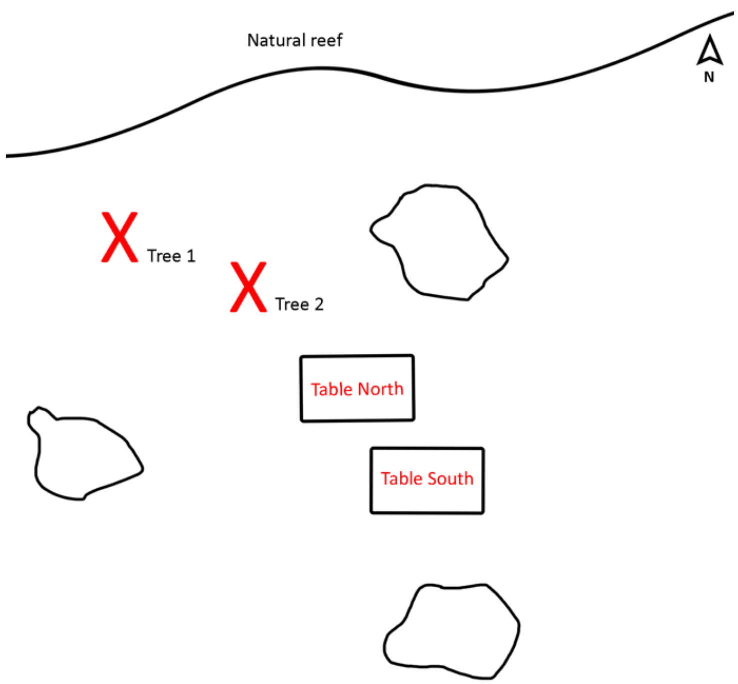
Figure 5. Tree 2

2.2 Ladder Bay

Fragments from the Black Rocks area were collected and transplanted to Ladder Bay on the 12th of March 2021. Water temperature was 26 degrees Celsius. The same protocol from Hole in the Corner was used for the fragments in Ladder Bay.

Species	**Origin**	**Original water Temp.**	**Original depth**	**Transplant Temp.**	**Transplant depth**
A. *Palmata*	Black Rocks	26 C	7.1 – 8.4 m	26 C	12 m
A. *cervicornis*	Coral outplant	26 C	17m	26 C	13 m
Orbicella	Black Rocks	26 C	9.5 – 10.1 m	26 C	13 m

The trial area was selected to be right next to the existing coral nursery since the nursery on Saba has been successful since 2015. This area is known to more sheltered for artificial structures to be anchored on sandy grounds. Also, this area seems to be a successful site since 2015 for *A. cervicornis* to be fragmented and nursed on artificial structures until they are grown big enough to be relocated to artificial reefs.

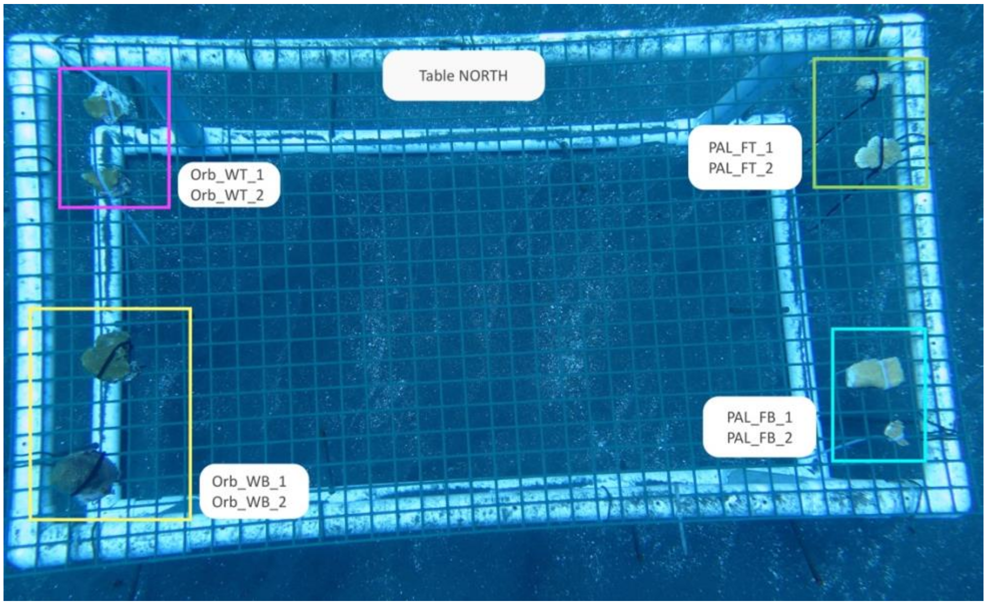


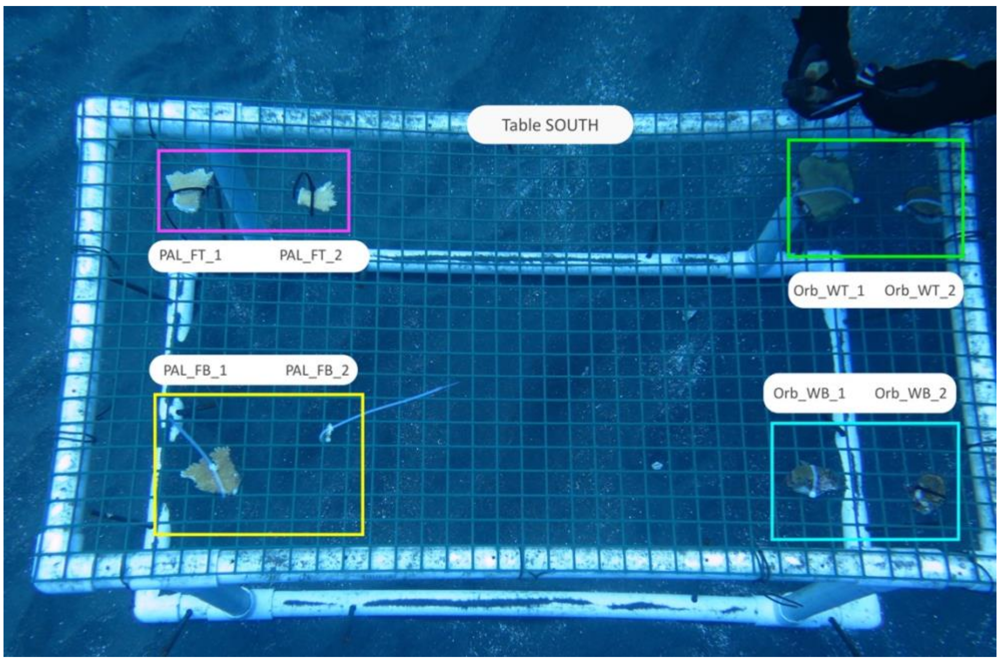
2.2.1 Tables

TABLE SOUTH					
Coding	**Description**	**Species**	**Relocation_Date**	**Health_Start**	**Health_Interim**
Orb_WT_1	Orbicella colony_WHOLE TOP_1	*Orbicella spp.*	12 March 2021	100%	80%
Orb_WT_2	Orbicella colony_WHOLE TOP_2	*Orbicella spp.*	12 March 2021	100%	80%
PAL_FT_1	Palmata_Fragment TOP_1	*Acropora palmata*	12 March 2021	100%	15%
PAL_FT_2	Palmata_Fragment TOP_2	*Acropora palmata*	12 March 2021	100%	15%
Orb_WB_1	Orbicella colony_WHOLE BOTTOM _1	*Orbicella spp.*	12 March 2021	100%	80%
Orb_WB_2	Orbicella colony_WHOLE BOTTOM_2	*Orbicella spp.*	12 March 2021	100%	80%
PAL_FT_1	Palmata_Fragment BOTTOM_1	*Acropora palmata*	12 March 2021	100%	15%
PAL_FT_2	Palmata_Fragment TOP_2	*Acropora palmata*	12 March 2021	100%	15%

TABLE NORTH					
Coding	**Description**	**Species**	**Relocation_Date**	**Health_Start**	**Health_Interim**
PAL_FT_1	Palmata_Fragment TOP_1	*Acropora palmata*	12 March 2021	100%	10%
PAL_FT_2	Palmata_Fragment TOP_2	*Acropora palmata*	12 March 2021	100%	10%
PAL_FB_1	Palmata_Fragment BOTTOM_1	*Acropora palmata*	12 March 2021	100%	10%
PAL_FB_2	Palmata_Fragment BOTTOM_2	*Acropora palmata*	12 March 2021	100%	10%
Orb_WT_1	Orbicella colony_WHOLE TOP_1	*Orbicella spp.*	12 March 2021	100%	90%
Orb_WT_2	Orbicella colony_WHOLE TOP_2	*Orbicella spp.*	12 March 2021	100%	90%
Orb_WB_1	Orbicella colony_WHOLE BOTTOM _1	*Orbicella spp.*	12 March 2021	100%	90%
Orb_WB_2	Orbicella colony_WHOLE BOTTOM_2	*Orbicella spp.*	12 March 2021	100%	90%

NOTE: Final mortality rate discussed in chapter “Health status of corals”



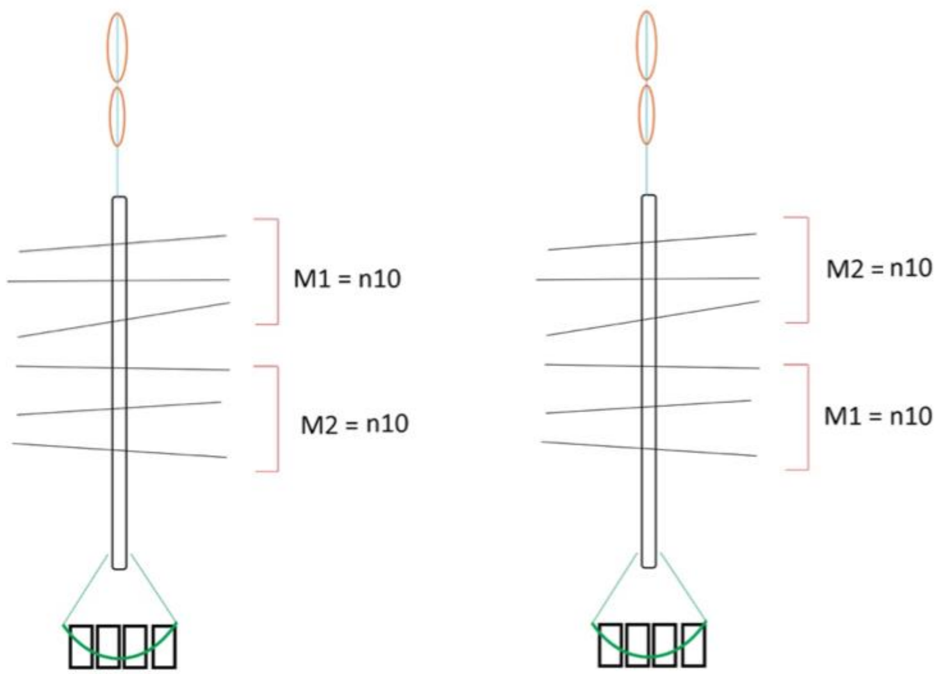


Fragments of Orbicella for Ladder Bay were collected only as whole colonies. For this site only whole colonies were transplanted and not fragmented. The same method was used for the A. palmata colonies as by Hole in the Corner.

2.2.2 Trees

A. cervicornis fragments were also collected on the same date from the coral nursery area and were transplanted to coral nursery tree. The trees at ladder bay/coral nursery site were placed close to the tables in the same set up as Hole in the Corner.

To prevent that all fragments from the same colony were placed on the same depth, fragments were divided evenly between two trees where the first half is placed on top of tree 1 and the other half is placed on the bottom of tree 2. The X-number of fragments were then randomly distributed between the tree branches to prevent that too many fragments are attached to only the top branches. For the trees at ladder bay both colonies were able to be divided in 20 fragments of each.



3 Health status of corals

Orbicella species have a low survival rate on the tables and at the end of the trial most *Orbicella spp*. fragments were deceased (+/- 80%). *Orbicella spp.* were also relocated as whole and fragmented. The fragments were attached with zip ties to the tables, which resulted in scouring and shaving by the zipties during currents. Experts from the Bahama's have recommended that the best way to relocate Orbicella spp. is by micro fragmenting the colonies and attaching them to coral plugs with epoxy. This prevents the colonies from scouring with zip ties, prevents from having a large piece of rock which makes the coral fragment unstable on the tables and has proven to be the way for the species to regenerate damaged tissue. Most of the colonies that were placed on the tables have had a very low survival rate due to the sedimentation settling on the tables. Moreover, it should be kept in mind that currently Saba is dealing with the Stony Coral Tissue Loss Disease (SCTLD), that affects *Orbicella* species greatly. Relocating these species puts the coral in much higher stress and more susceptible to being infected by SCTLD.

A. palmata colonies were placed between the minimum and maximum proposed depth to evaluate the survival rate. Most fragments were placed closer to the maximum depth. Survival rate at the start of the trail at Hole in the Corner was higher due to less algal growth and sedimentation rate on the tables, trees and natural reef. Hole in the Corner has less sedimentation settlement due to the location relative to the island the average direction of the currents. However, at the end of the trial all *A. palmata* colonies on the tables were deceased and only the fragments that were relocated to the natural reefs in Hole in the Corner have survived. *A. plamata* colonies are better off attached to the natural reefs with epoxy to prevent scouring by the zipties on the tables and the natural reefs are also a bit shallower than the tables. Through the years during the RESCQ project *A. palmata* fragments were placed on coral nursery trees and natural reefs in 2015 at Ladder Bay and have not survived at that location. Historically, *A. palmata* colonies usually occur on the South, East and North of Saba, and shallow areas near Torrents Point.

Coral nursery trees are still the most suitable for the relocation of *A. cervicornis* for both locations. Most of the *A. cervicornis* fragments are doing well at Ladder Bay as well as Hole in the Corner. Sedimentation rate in Ladder Bay is much higher than in Hole in the Corner. Historically, *A. cervicornis* species on Saba occur relatively deeper than neighboring islands and have known to occur in large patches on the South side of the island, where Hole in the Corner is located. Looking at historical data and survival rate of previous studies and experiments (Ginger et al. 2017) the most successful areas for relocating *A. cervicornis* has proven to be Big Rock Market at a depth between 15-18m, where the substrate is also remnants of previous large *A. cervicornis* colonies. Some fragments were also very small fragmented (< 20cm) which could also have played a role in how much faster the fragments grow. However, this did not have an effect on the mortality rate of the relocated corals.

4 Recommendations

General monitoring, structures and upkeep

- Monthly checkup and cleaning of the relocation trial structures, monitoring of the health status of the coral fragments.
- Iron frames with zincs should be considered since it promotes less algal growth.
- Relocation of coral should only be done in low water temperatures (lower than 26-27 C).
- Relocation of corals species should only be done to sites where historically the species used to occur or where remaining of old colonies can be found.

Orbicella

- A minimum of 6 months consecutive monitoring to determine the actual survival rate of *Orbicella species* on natural reefs.
- Micro fragmenting should be considered for *Orbicella* species.
- *Orbicella* species should be relocated to natural reefs.

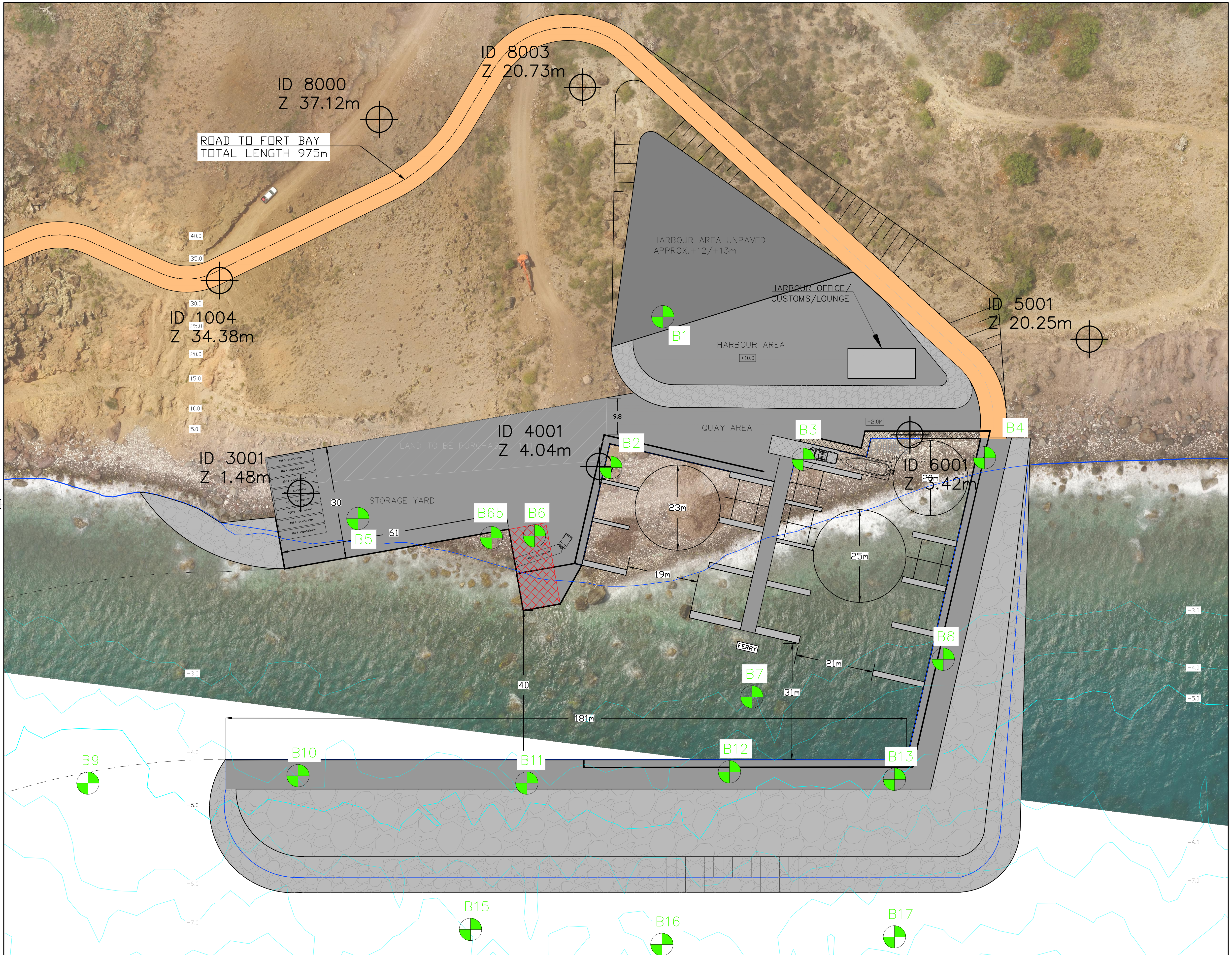
Palmata

- Colonies should only be transferred to natural reefs, either as whole colonies or fragmentation.
- Micro fragmenting these corals onto coral plugs should also be considered.

Cervicornis

- Cervicornis should be relocated to coral nursery tree structures in Hole in the Corner or at the out-planting site at Big Rock Market where out planting has been marked as successful since 2018.
- Fragments should not be smaller than the recommended size of 20 cm.

Annex 3: Overview of sampling points and sample types (map and table)



LEGEND

Executed Borehole

Benchmark

Borehole ID (as-built)	Easting [UTM20N]	Northing [UTM20N]
B1	474560.3	1947595.3
B2	474546.4	1947555.1
B3	474597.7	1947557.3
B4	474646.0	1947557.7
B5	474479.0	1947541.5
B6	474526.0	1947536.9
B6b	474514.6	1947536.4
B7	474584	1947494
B8	474635	1947504
B9	474407	1947471
B10	474463	1947473
B11	474524	1947471
B12	474578	1947474
B13	474622	1947472
B15	474509	1947432
B16	474560	1947428
B17	474622	1947430

0 25 m 50 m

BLACK ROCKS HARBOUR – BOREHOLE LAYOUT AS-BUILT (15 SEPT 2020)

Itemref	Quantity	Title/Name, designation, material, dimension etc		Article No./Reference	
Designed by XXX	Checked by XXX	Approved by - date XXX - 00/00/00	Filename XXX	Date 00/00/00	Scale 1:1
XXX		XXX			
		x		Edition 0	Sheet 1/1

RevNo | Revision note | Date | Signature | Checked

Project : Black Rock Harbour
Project nr: GC 20001
Date : September 2020
Location : Saba
Subject: Proposed Sample selection

SAMPLE ID	Depht-surface	Sample type	UCS + BD	BTS	Vol. Weight	Specific density	PSD	CaCo 3	Min/max den	Organic content	Proctor test (mpd)	CBR	Chemical - Pakket A***	Chemical - Pakket C3****
BH 1	0.3-2.0	D/ Sand			1	1	1	1						
BH 1	3.0-3.5	C/ Pink Andesite	1	1										
BH 2	1.3-1.5	C/ grey Andesite	1	1										
BH 3	6.2-7.0	D/ Sand			1	1	1	1						
BH 5	6.7-6.9	C/ Red Andesite	1											
BH 6B	0.5-0.7	C/ Pink/grey Andesite	1	1										
BH 7	3.0-4.5	D/ Sand			1	1	1			1				
BH 7	7.0-8.0	D/ Sand			1	1	1	1						
BH 7	3.0-8.0	D/ Sand composite							1*					
BH 8	4.0-6.0	D/ Sand composite			1	1	1			1				
BH 9	1.0-1.5	D/Sand					1	1						
BH 9	6.3-7.5	D/Sand			1	1	1			1				
BH 10	4.3-4.45	C/ dark red Andesite	1											
BH 10	6.0-8.0	D/Sand			1	1	1	1						
BH 11	0.7-1.1	D/Sand												1.1**
BH 11	1.45-1.6	C/Limestone	1	1										
BH 12	3.0-3.5	D/Sand					1	1						
BH 12	7.0-8.0	D/Sand			1	1	1							
BH 15	1.1-2.0	D/Sand								1				1.2**
BH 16	3.5-8.2	D/Sand			1	1	1	1		1				
BH 17	0-0.25	C/Coral limestone	1	1										
BH 17	0.5-0.7	C/Coral limestone	1	1										
BH 17	2.0-2.2	C/Coral limestone	1	1										
ROAD - DCP1	0-1m	0/20mm road base material									1	1		
ROAD - DCP3	0-1m	0/20mm road base material					1				1	1		
ROAD - DCP5	0-1m	0/20mm road base material									1	1		
ROAD - DCP6	0-1m	0/20mm road base material									1	1		
LAND 1	surface	mixed sand sample from land surface											1	
LAND 2	1m	mixed sand sample from beach trial pits					1**							
WATER 1	surface	mixed sand from sea bed surface												1

* Mixed sand sample from core to determine min/max density (relevant for potential re-use in reclamation/breakwater)
** Mixed sample from BH11 and BH15 for chemical analysis

*** **A-pakket**: landbodem (lutum, organische stof, zware metalen (arseen, cadmium, chroom, koper, kwik, nikkel, lood en zink), minerale olie, som PAK, EOX
******C3-Pakket**: Waterbodem uit zout rijksoppervlaktewater: droge stof, lutum, organische stof, zware metalen (arseen, cadmium, chroom, koper, kwik, nikkel, lood en zink), minerale olie (GC), PAK (10 VROM), OCB's en PCB's en TBT.

Total	UCS + BD	BTS	Vol. Weight	Specific density	PSD	CaCo 3	Min/max den	Organic content	Proctor test (mpd)	CBR	Chemical - Pakket A***	Chemical - Pakket C3****
Total	**9**	**7**	**9**	**9**	**13**	**7**	**1**	**5**	**4**	**4**	**1**	**2**

Annex 4: Laboratory results (chemical, physical)

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VOOR GROND- EN GRONDWATER
2e Hogeweg, Zeist
The Netherlands

SOIL INVESTIGATION

Black Rock Harbour
SABA

2021

Geotron International report nr. GR 20001

GEOTRON INTERNATIONAL B.V
ONDERZOEKSBURO VOOR GROND- EN GRONDWATER
2e Hogeweg
Zeist, The Netherlands

Principal	:	Openbaar Lichaam Saba
Consultant	:	Witteveen + Bos
Report nr.	:	GR 20001
Project nr.	:	GIO 20001
Date	:	January 2021
Version	:	Revision_1

SOIL INVESTIGATION

Black Rock Harour
SABA

2021

Geotron International report nr. GR 20001

Reported by: [redacted]
Authorization by: [redacted]

1 CONTENTS

Appendices

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2 INTRODUCTION

By order of Openbaar Lichaam Saba, Geotron International B.V., onderzoeksbureau voor grond en grondwater, performed a soil investigation for the harbour construction at Black Rock, Saba.

The island of Saba is located in the eastern Caribbean and is part of the Windward Islands. An aerial image of the island is shown in Figure 2-1.

Scope of the work is presented in the Geotron International BV Quote GIO 19165V01 dated 29 September 2019, to W + B, for these investigations the representative of the Principal.

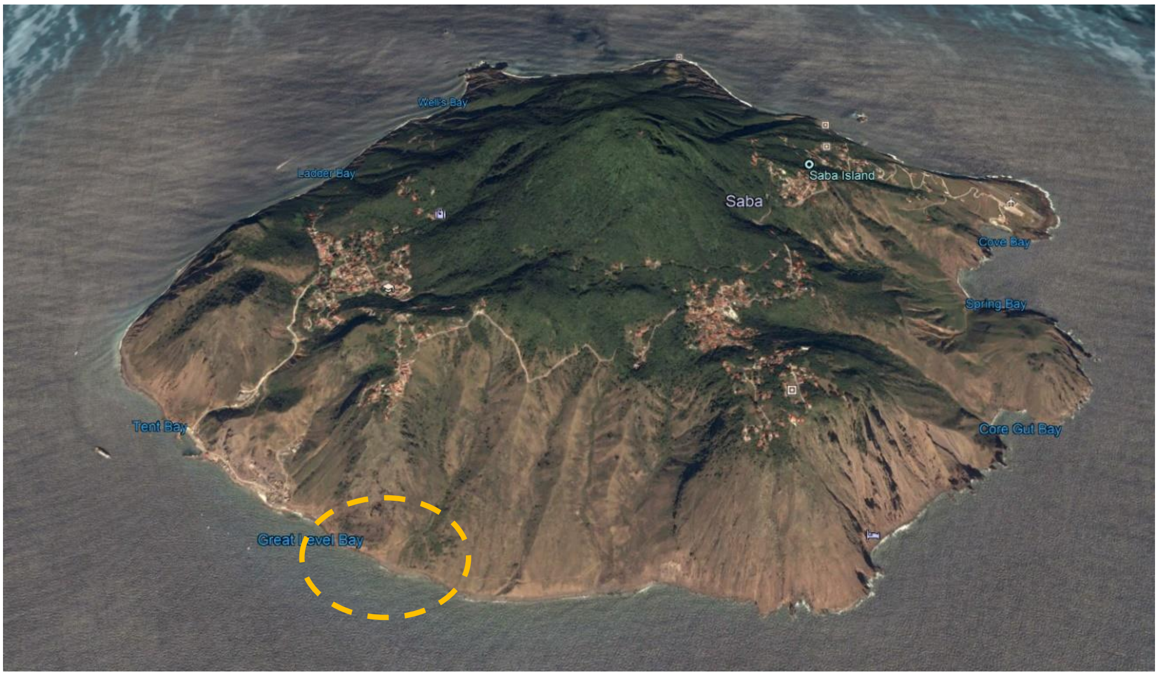


Figure 2-1 Saba, project location indicatively shown by dashed circle (source: Google Earth)

The work consisted of a geotechnical on-shore and underwater survey with 17 borehole drillings and a number of (intermediate) Dynamic Penetration measurements within the boreholes, followed by a laboratory investigation on obtained soil and rock samples.

In this report the factual findings of the investigations are presented.

The following authorities / companies are involved in this project:

- Principal:	Openbaar Lichaam Saba
- Consultant:	Witteveen + Bos
- Geotechnical investigation:	Geotron International BV

3 SOIL INVESTIGATION

3.1 General

The objectives of the current investigations are to collect sufficient information of the soil properties, to serve as basis for the conceptual design of Black Rock Port.

The geotechnical survey of rotary core drillings and in-situ tests are executed during non-consecutive periods in the year of 2020. The project could not be executed in a single phase due to weather and covid-19 restraints.

The location of the boreholes is indicated in Figure 3-1. Seven boreholes are executed onshore and ten locations are situated nearshore.

The laboratory investigation on collected soil and rock samples was performed in November and December 2020.

The locations of the investigation points are registered with an RTK system, elaborated in the next paragraph.

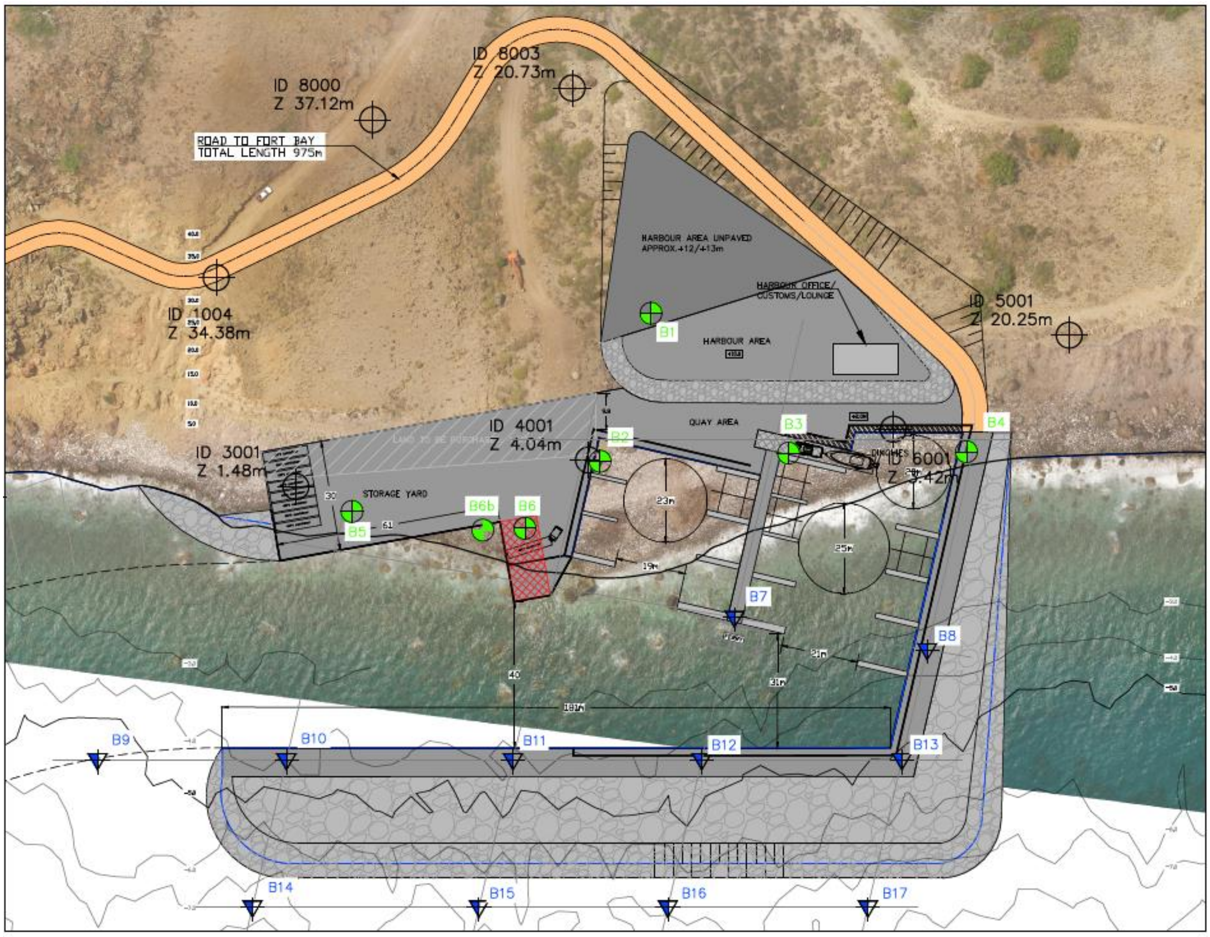


Figure 3-1 Location of boreholes, BH14 optional and not executed in current campaign

3.2 Topographical survey data

The location of the soil investigation points are determined with an RTK system, whereby the grade and bottom levels of the boreholes are correlated to the known local reference elevation, i.e. NMP (Normaal Midden Peil). The co-ordinates and elevations of the boreholes are summarized in Table 3-1.

Table 3-1 Coordinates and elevations of borehole locations

Location	Easting	Northing	Elevation [m NMP]
B1	474560.3	1947595.3	10.69
B2	474546.4	1947555.1	4.01
B3	474597.7	1947557.3	2.13
B4	474646.0	1947557.7	1.18
B5	474479.0	1947541.5	1.13
B6	474526.0	1947536.9	1.58
B6b	474514.6	1947536.4	1.49
B7	474583.0	1947512.7	-3.00
B8	474635.3	1947503.9	-3.50
B9	474409.8	1947474.0	-5.60
B10	474461.2	1947474.0	-4.40
B11	474522.7	1947474.0	-4.60
B12	474574.0	1947474.0	-5.30
B13	474628.4	1947474.0	-5.30
B15	474513.5	1947434.0	-6.80
B16	474564.8	1947434.0	-7.00
B17	474619.2	1947434.0	-7.60

3.3 Geotechnical investigation

The in-situ tests consists of rotary coring with Dynamic Penetration Tests (DPT) in gravelly and sandy deposits. The survey complies with the actual standards ISO, BS and Eurocode.

DPT are executed to determine the blow-count N_{10} value (refer to paragraph 3.3.2) in order to get information about the density and/or consistency of the soil.

Each borehole was protected by a casing. Disturbed samples are recovered from the granular sediments. Coring was performed with the BQTK wireline coring technique, obtaining samples with a diameter of 40 mm. Cores are stored in dedicated core boxes. The applied borehole diameter, i.e. outer casing diameter equals 53 mm.

3.3.1 Records and observations

For each borehole a record is made, according to standard BS5930:1999.

On site, the following drilling data are gathered by the drilling engineer, in Appendix B these data are presented in the drilling logs:

- Depth levels sampling and testing;
- Depth levels sampling and testing;
- General description of basic material, with the following classification for coarser granular material;
    - Large Boulder > 630 mm;
    - Boulder 200 – 630 mm;
    - Cobble 63 – 200 mm;
    - Pebble 2 – 63 mm.
- DPT results:
    - Dynamic Penetration test (DPL-5) results in granular sediments;
        - Area of cone: 5 cm^2;
        - Hammer mass: 10 kg;
        - Hammer fall height: 50 cm;
        - Registration depth: each 10 cm;
        - Blow-count, N-value: N_{10}.

The boring locations are given in Appendix A. For the results of the field work see Appendix B (borehole logs) and Appendix C (photographs of core runs).

3.3.2 Laboratory work

The selected samples are transported by air to Geolabs UK for examination and testing.

Laboratory testing is performed during the months of November and December 2020 and includes:

11 Particle size distribution;
9 Pycnometer tests (specific gravity);
7 Carbonate contents;
5 Organic content tests;
1 Minimum/maximum density;
1 Chemical analysis (land surface);
2 Chemical analyses
9 Unconfined Compression Tests (UCS);
7 Indirect tensile strength by the Brazilian tests (BTS).

The samples consist of varying soils and rock, as presented in chapter 5. One chemical test is conducted on material from land surface and two tests are performed on seabed material, presented in Appendix F (results partly presented in Dutch language).

In Table 3-2 a global relation between the UCS and rock strength classifications is given.

Table 3-2 Rock strength classification (Pianc and British standard)

Term	Unconfined Compressive Strength (MPa)	Field estimation of strength
Extremely strong rock	> 200	Rock rings on hammer blows, Sparks fly. Only broken by sledgehammer.
Very strong rock	100 - 200	Rock chipped by heavy hammer blows (Dull ringing sound)
Strong rock	50 - 100	When resting on solid face, rock can be broken by hammer blows.
Moderately strong rock	12.5 – 50	When held in hand, rock can be broken by hammer blows.
Moderately weak rock	5 – 12.5	Only thin slabs, corners or edges can be broken off with heavy hand pressure.
Weak rock	1.25– 5	Material crumbles under firm blows of geological hammer, can be shaped with knife. Gravel size lumps can be broken in half by heavy hand pressure.
Very weak rock	< 1.25	Indented by thumbnail. Gravel size lumps can be crushed between finger and thumb.

No direct parameter measurements on the granular materials were conducted for the current project.

All testing results are presented in Appendix D.

3.4 Dynamic Penetrometer Tests

In Table 3-3 a global relation between the Dynamic Penetration Test (DPT) and the soil consistency / density is given.

Table 3-3 Global relation between DPL-5 N_{10}-value and consistency/density of the soil

DPL-5 N_{10}-value in clay	Consistency	DPL-5 N_{10}-value in sand	Relative density
< 2	very soft	< 3	very loose
2 - 4	soft	3 - 10	loose
4 - 8	firm (medium soft)	10 - 30	medium dense
8 - 15	stiff	30 - 50	dense
15 - 30	very stiff	> 50	very dense
> 30	hard		

From the obtained sounding data, i.e. blow counts per 10 cm penetration N_{10}, the following soil parameters could be assessed [3] and [9]:

- The dynamic cone resistance q_{dyn} in MPa;
- The static cone resistance q_c in MPa;
- The relative density I_D of the granular material in %.

The dynamic cone resistance can be determined using the following relation [6]:

$$q_{dyn} = \left(\frac{m}{m + m'}\right)\frac{m \cdot g \cdot h}{A \cdot e}$$

Where:

m	Mass of the DPT hammer;
m'	Mass of the anvil and rods;
g	Acceleration due to gravity;
h	Falling height of the DPT hammer;
N_{10}	Number of blows per 10 cm penetration;
A	Base area of the sounding cone;
e	Average penetration per blow, $= 0.1/N_{10}$.

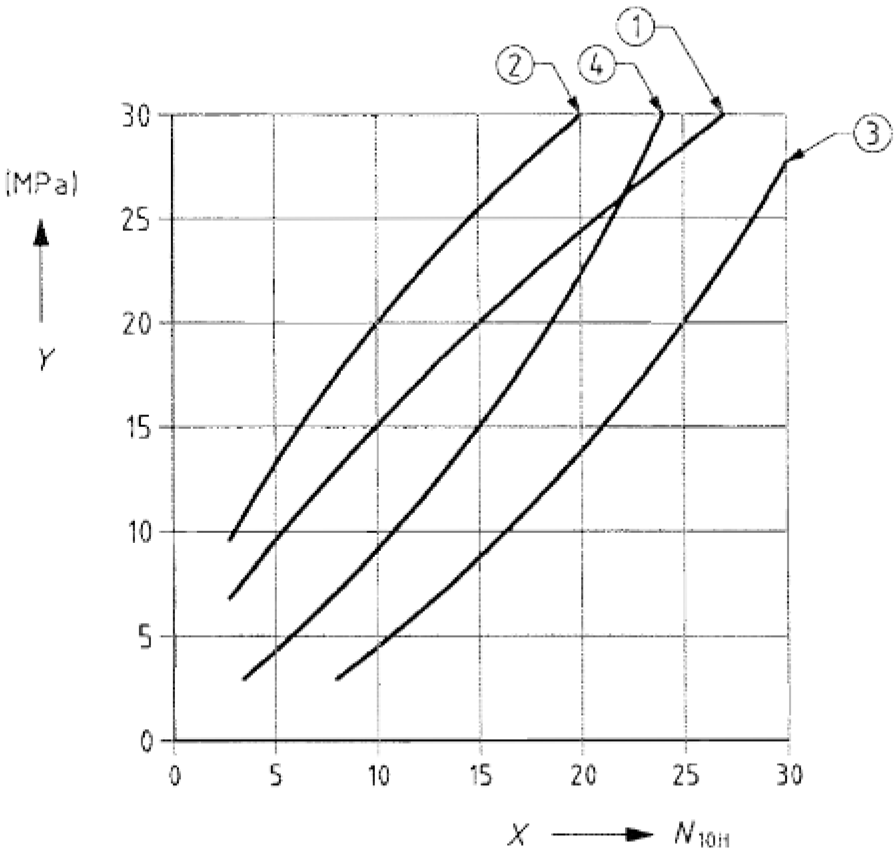
Based on the N_{10}, the relative density can be estimated. For the relative density the following levels of compaction are used:

Very loose	$0 \ < I_D < 15\%$
Loose	$15 < I_D < 35\%$
Medium	$35 < I_D < 65\%$
Dense	$65 < I_D < 85\%$
Very dense	$85 < I_D < 100\%$

The result of the correlations are presented in Table 3-4.

For an initial assessment the DPT blow-count can be correlated to static cone resistance (CPT) q_c in MPa using Figure 3-2 [6]. For the assessment line 4 is used (refer to paragraph 5.2.3). This is considered a conservative approach taking into account the relatively low coefficient of uniformity ($C_u = 3.3$) and the fact that poorly graded material (line 2) will lead to higher) q_c values.

Note that Figure 3-2 requires N_{10} based on DPT heavy type, these values are back-calculated based on the dynamic cone resistance q_{dyn}.



Key

(x) Number of blows, (y) Cone penetration resistance (q_c),
1 Poorly-graded sand above groundwater,
2 Poorly-graded sand below groundwater,
3 Well-graded sand and gravel above groundwater,
4 Well-graded sand and gravel below groundwater.

Figure 3-2 Relation q_{dyn} and q_c for varying granular materials [6]

The results are summarized in Table 3-4. For each assessment the refusal interval ($N_{10} \geq 50$) is not taken into account in the averages.

It is emphasized that the soil data of table 2.3.2. need to be handled with care, because the parameters are based on empirical correlations for mainly silica sands [3].

Table 3-4 Assessment of soil parameters from DPT tests in granular soil; mainly based on empirical correlations for silica sands

DPL-5	Elevation	Depth		Dynamic cone resistance q_{dyn}	Static cone resistance q_c	Relative density I_D
	[m NMP]	[m] from	[m] to	[MPa]	[MPa]	[%]
BH01	10.7	1.5	1.7	15	10	62
BH01	10.7	5.5	5.7	15	15	68
BH02	4.0	7.0	7.3	-	-	-
BH03	2.1	7.1	7.6	8	9	60
BH06	1.6	4.5	4.7	14	13	65

DPL-5	Eleva-tion	Depth		Dynamic cone re-sistance q_{dyn}	Static cone re-sistance q_c	Relative density I_D
	[m NMP]	[m] from	[m] to	[MPa]	[MPa]	[%]
BH06b	1.5	4.5	6.6	13	13	65
BH11	-4.6	3.0	3.1	25	23	73
BH13	-5.3	1.5	1.7	10	7	57
BH15	-6.8	1.5	1.6	9	7	55
BH16	-7.0	1.5	1.6	7	5	51

- direct refusal; no parameter derived
** medium to coarse gravel*
***boulders*

4 SITE GEOLOGY

The island of Saba is situated in a relatively active part of the northern Lesser Antilles island arc and has young volcanic formations.

Saba is a rhomb shaped island with an area of only 13 sq. km and consists of a single volcano measuring 4.6 km east to west and 4.0 km north to south, rising to a central peak of Mt. Scenery at 887m. The appearance of the island is that of a deceptively simple stratovolcano, but this is not the case as it has been built up of a large number of Pelean domes with their aprons of coarse pyroclastic deposits that form a distinctive shoulder on the island at about 450 to 500 m above sea level.
The island is essentially a complex of Andesite Pelean domes with their aprons of eruptive material such as block and ash flow deposits, together with a few domes that have produced short thick dome flows that are steeply inclined on the island slopes [4].

The island appears to overlie a NE-SW fault zone as indicated by recent seismic activity and the distribution of hot springs along the longest axis of the island.

It can be seen in Figure 4-1, where the project location is indicated, that multiple gullies run downwards to the foreseen harbour area [1].

It is concluded that the site is located on sedimentary deposits of fluviatile and scree (slope debris) origin, i.e. volcanic blocks, gravels, and sands with locally coral limestone beds, lying on terraces of volcanic rock.

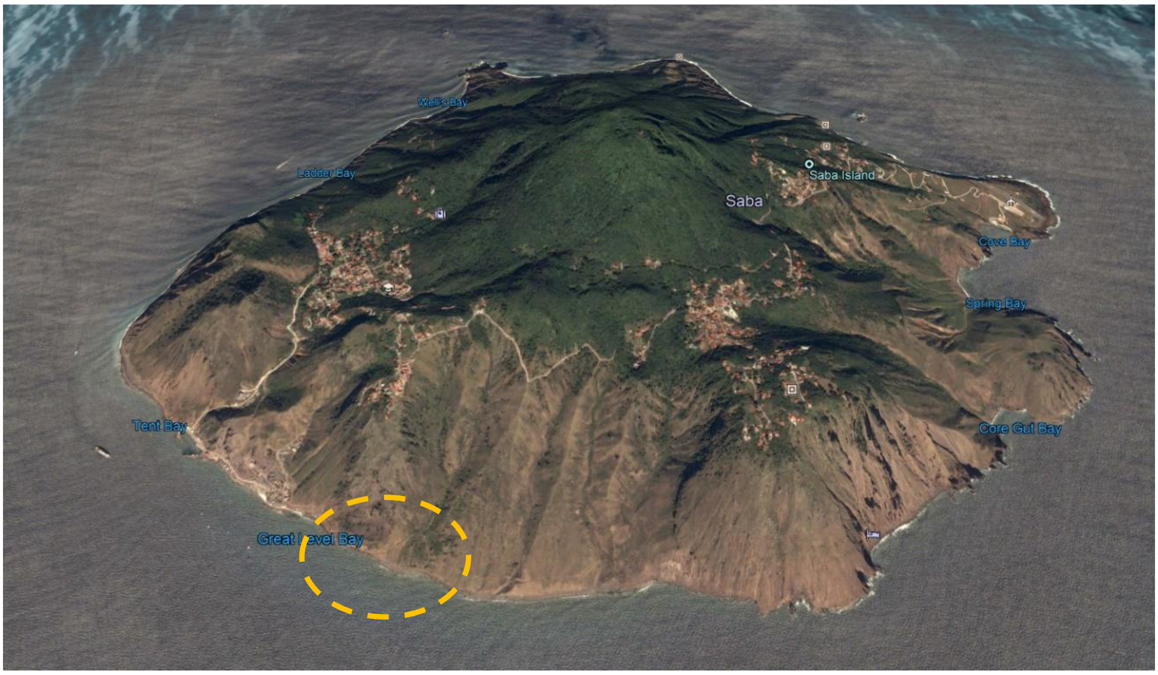


Figure 4-1 Island of Saba. Steep slopes to the shore line around project location (indicatively shown by dashed circle) and the gullies running to the shoreline (source: Google Earth)

5 RESULTS OF SOIL INVESTIGATION

5.1 General

The encountered ground conditions are fairly variable, especially in relation to the highly erratic stratification of the various ground types. This spatial variability is particularly evidenced in boreholes BH06 and BH06b, which are located at approximately 12 m distance. BH06 records mostly gravel and cobles with boulders while in BH06b large intervals of (loose) sand are encountered.

5.2 Results geotechnical survey

The soil and rock deposits encountered at the project site are described in paragraph 5.2.1 to 5.2.4.

5.2.1 Boulders and Cobbles

Boulders and cobbles are most predominant and consist of reddish brown to grey, fresh to slightly weathered Andesite The voids between the boulders and cobbles are partly filled with a sand and gravel matrix.

The dry bulk density of the andesite averages approximately 2.3 Mg/m^3. The Andesite is classified in the laboratory as a moderately weak to strong rock (according to Table 3-3) or low to moderate strength according to ISRM, with Unconfined Compression Strengths between 8.9 MPa and 65.6 MPa.

Based on the results of the laboratory analyses a statistical assessment is made. For density the average values are calculated and for strength parameters the 95% reliable mean value is used for the Andesite boulders. The characteristic values are derived according to [5] and given below.

Table 5-1 Results of the laboratory analyses on rock cores; bulk density parameters

Rock type	Unsaturated bulk density Mg/m^3			Laboratory moisture bulk density Mg/m^3		
	Min.	Max.	Mean	Min.	Max.	Mean
Andesite boulders	1.88	2.47	2.30	1.97	2.48	2.34

Min. minimum value as measured
Max. maximum value as measured

The variation coefficient for the unsaturated and laboratory moisture bulk densities are relatively low with values of approx. 8%.

The results of the strength parameter determination are summarized in Table 5-2 (UCS) and Table 5-3 (BTS).

Table 5-2 Results of the laboratory analyses on rock cores; Unconfined Compression Strength

Rock	**Unconfined Compression Strength q_u [MPa]**			
	Min.	**Max.**	**Mean**	**Low representative of the Mean**
Andesite boulder	8.9	65.6	36	7.4

Min. *minimum value as measured*
Max. *maximum value as measured*

Notable is the relatively large coefficient of variation of 64 % for the Unconfined Compression Strength.

Figure 4.1 presents the correlation between the measured dry densities and the corresponding UCS-values. The regression line equation equals $q_u = 85\rho_{dry} - 157\ MPa$ where ρ_{dry} equals the dry density in Mg/m^3.

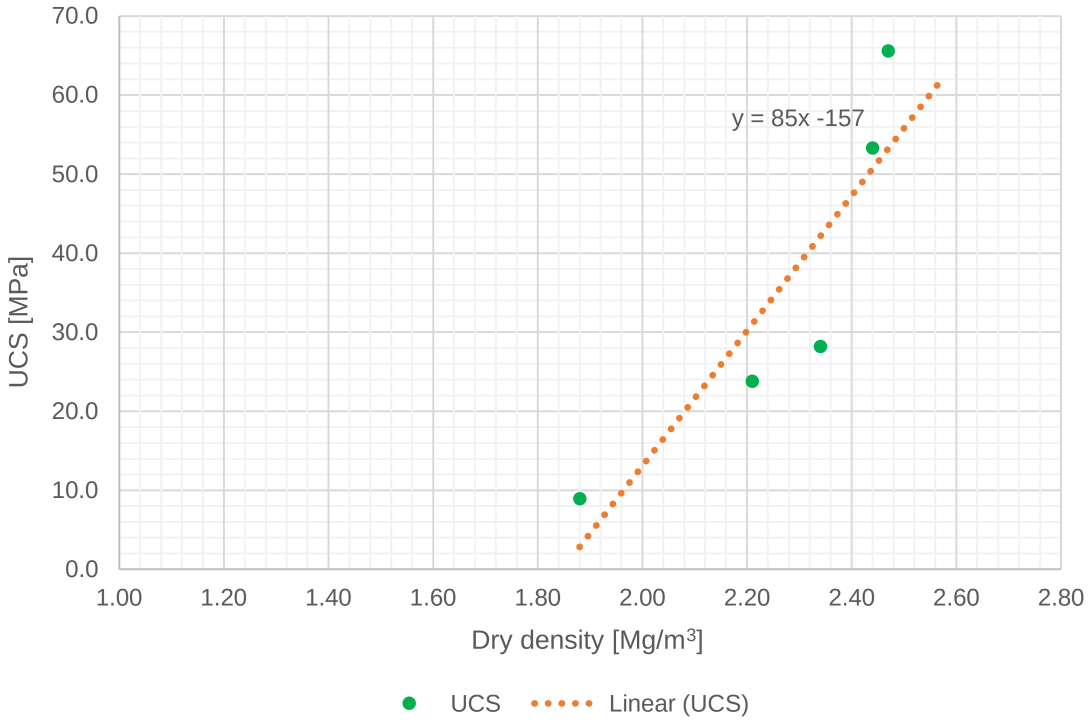


Figure 5-1 Correlation between Dry density and Unconfined Compression Strength; Saba Andesite

Table 5-3 shows the BTS data for andesite rock. It is noted that due to the low number of tests no reliable statistical assessment can be made and a coefficient of variation $CV = 0.2$ is assumed.

Table 5-3 Statistical interpretation of the BTS tensile strength data

Rock	**Indirect Tensile Strength (Brazilian method) [MPa]**			
	Min.	**Max.**	**Mean**	**Low representative of the Mean**
Andesite boulder	2.9	8.0	5.4	2.7*

* *assuming CV=0.2*
Min. *minimum value as measured*
Max. *maximum value as measured*

5.2.2 Cobbles, pebbles and (sandy) gravel

These deposits are in general moderately to dense packed and are sometimes included in a sand matrix.

5.2.3 Sands and gravel, locally cobbles, pebbles and coral fingers

These granular deposits, in general gravelly sands, are mostly concentrated in the direction of the existing breakwater.

The relative densities are estimated as medium dense, with locally looser and denser zones.
The loose packed zones are relatively thin and are encountered in boreholes BH01 (NMP-7.2 to -7.1 m) BH06 (NMP-1.4 to -1.5 m), BH6b (NMP-0.1 to -1.6 m), BH12 (NMP-8.3 to -12.4 m), BH13 (NMP-8.1 to -8.5 m).

The specific gravity of the gravelly sand, with locally shell fragments, equals on average 2.76 Mg/m^3, with a coefficient of variation of less than 1%. The organic content is generally low (<0.4 %) however at BH16 a sample from 3.5-8.2 m depth shows 11% organic content. The carbonate content varies between less than 0.1% in BH01, BH03 and BH07 up to 27% in BH09.

Figure 5-2 shows the results from PSD as well as the average PSD based on all results except the two outliers shown in the graph (far left and far right). The fines content (silt + clay, defined as material <63 µm) equals 4%, sand 91% and gravel 4% on average.

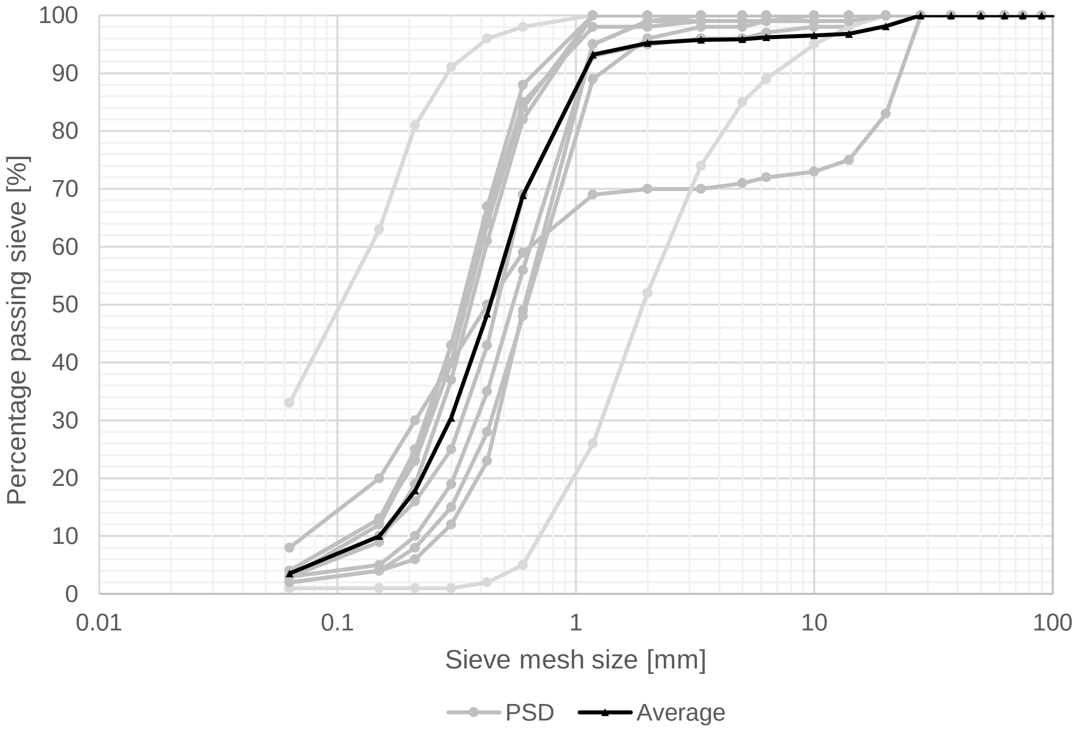


Figure 5-2 Summary graph PSD results

With the results shown in Figure 5-2 a coefficient of uniformity $C_u = \frac{D_{60}}{D_{10}} = \frac{0.5}{0.15} = 3.33$ and coefficient of curvature $C_c = \frac{{D_{30}}^2}{D_{10} \cdot D_{30}} = \frac{0.3^2}{0.15 \cdot 0.5} = 1.1$ can be determined. With these values the material can be described as well graded.

On the material from this zone a minimum/maximum density test was performed. The test specimen consists of a mixture of material from BH07, taken from NMP-6 to -11 m. The results are shown in

Table 5-4.

Table 5-4 Results min/max density tests

Sand	Minimum density	Maximum density
	Mg/m³	Mg/m³
Mixture BH07	1.16	1.50

5.2.4 Coral limestone

Coral limestone is encountered to varying extent in all offshore boreholes except BH13. Particularly in BH17 multiple meters of coral limestone of varying cementation are observed. In general the limestone is medium to poor cemented and medium grained.

Occasionally andesite gravel can be observed in the limestone cores. Particularly at BH07 and BH08 the coral limestone is present as a cementation of andesite gravel. In BH09 a coral limestone layer of approx. 20 cm is observed, it cannot be confirmed whether this belongs to a limestone layer or consists of an isolated piece.

The dry bulk density of the limestone varies significantly and averages approximately 1.97 Mg/m³. The rock is classified as a moderately weak to moderately strong rock (according to Table 3-3) or low to moderate strength according to ISRM, with Unconfined Compression Strengths between 1.6 MPa and 23.9 MPa.

Based on the results of the laboratory analyses a statistical assessment is made. For density the average values are calculated and for strength parameters the 95% reliable mean value is used for the Andesite boulders. The characteristic values are derived according to [5] and given below.

Table 5-5 Results of the laboratory analyses on rock cores; bulk density parameters

Rock type	Unsaturated bulk density Mg/m³			Laboratory moisture bulk density Mg/m³		
	Min.	Max.	Mean	Min.	Max.	Mean
Limestone	1.35	2.25	1.97	1.67	2.55	2.16

Min. minimum value as measured
Max. maximum value as measured

The variation coefficients for the unsaturated and laboratory moisture bulk densities are 13% and 17%, respectively.

The results of the strength parameter determination are summarized in Table 5-6 (UCS) and Table 5-7 (BTS). It is noted that due to the low number of tests no reliable statistical assessment can be made and a coefficient of variation $CV = 0.2$ is assumed for both UCS and BTS results.

Table 5-6 Results of the laboratory analyses on rock cores; Unconfined Compression Strength

Rock	Unconfined Compression Strength q_u [MPa]			
	Min.	Max.	Mean	Low representative of the Mean
Limestone	1.6	23.9	14.6	10.0*

** assuming CV=0.2*
Min. minimum value as measured
Max. maximum value as measured

Notable is the relatively large coefficient of variation of 75 % for the Unconfined Compression Strength.

Figure 4.1 presents the correlation between the measured dry densities and the corresponding UCS-values. The regression line equation equals $q_u = 24\rho_{dry} - 30\ MPa$ where ρ_{dry} equals the dry density in Mg/m^3.

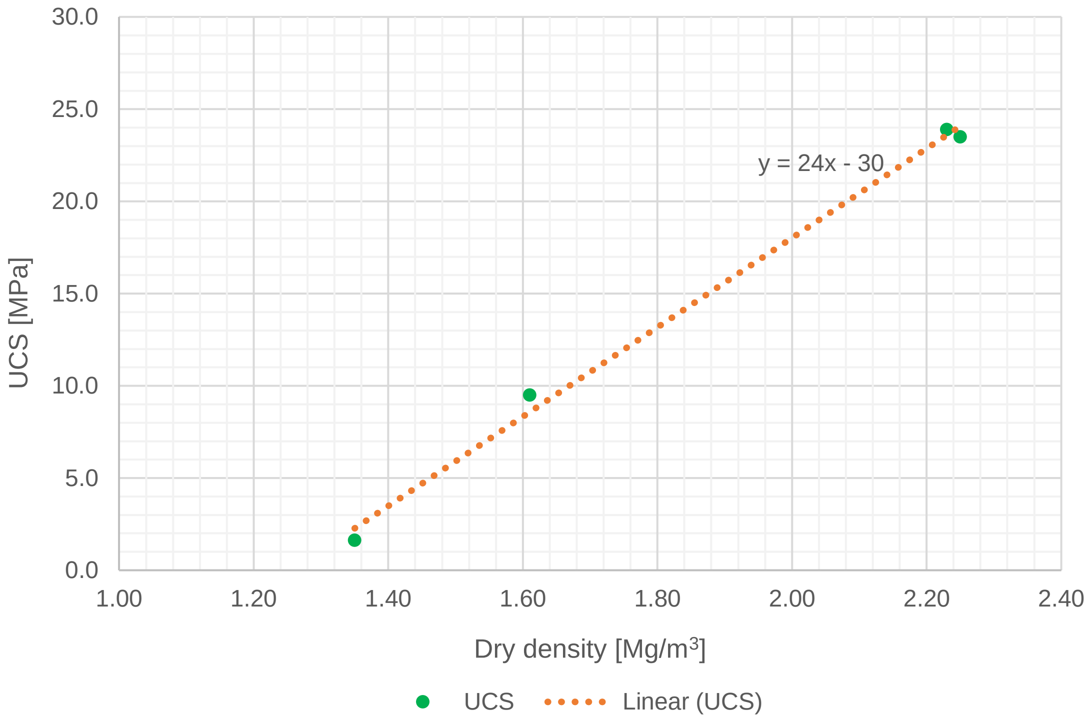


Figure 5-3 Correlation between Dry density and Unconfined Compression Strength; Saba Limestone

Table 5-7 Statistical interpretation of the BTS tensile strength data

Rock	Indirect Tensile Strength (Brazilian method) [MPa]			
	Min.	Max.	Mean	Low representative of the Mean
Limestone	0.2	5.5	3.8	2.6*

*	*assuming CV=0.2*
*Min.	minimum value as measured*
*Max.	maximum value as measured*

6 SEISMIC CONDITIONS

The eastern Caribbean island arc is located on a convergent plate boundary where two tectonics plates meet and the denser Americas Plate is forced beneath the lighter Caribbean Plate. This is the main cause of the volcanic and seismic activity in the area.

The University of the West Indies studied the earthquake hazard for the Leeward Islands and considered the island of Saba to have a moderate to high hazard for earthquakes. The Peak Ground Acceleration (PGA) is assessed (John B. Shepperd, 1996) on approximately 2.5 m/sec^2 , having 10% probability of exceeding in 50 years. This acceleration corresponds with a return period of 475 years. The probabilities refer to the levels of acceleration on firm ground (solid rock).

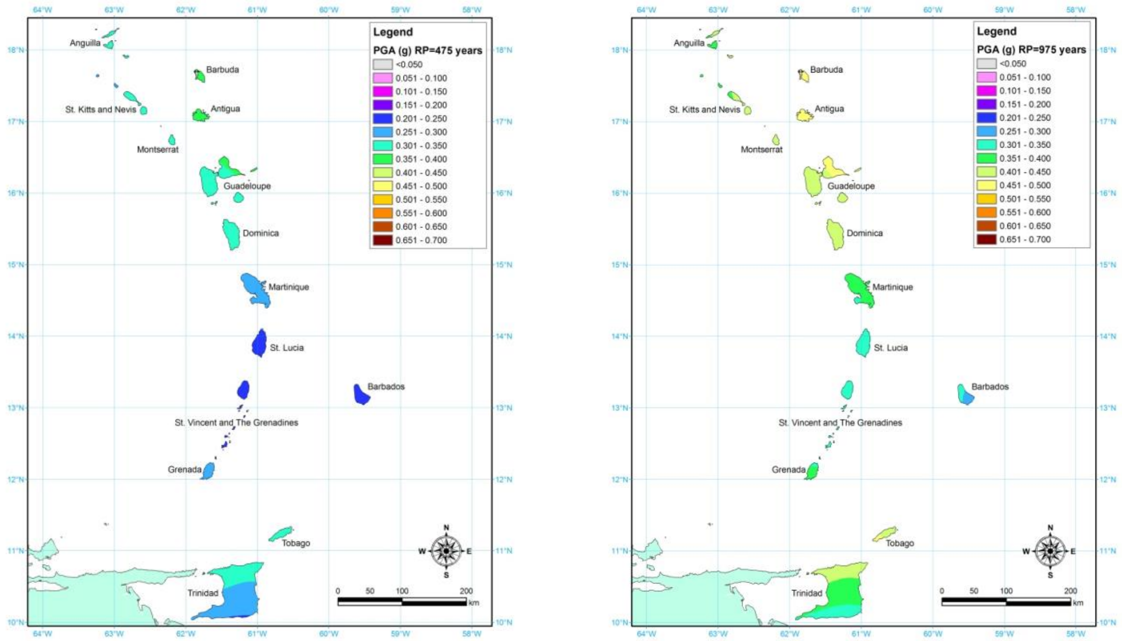


Figure 6-1 Peak ground accelerations for the eastern Caribbean Island arc. Source UWI Trinidad

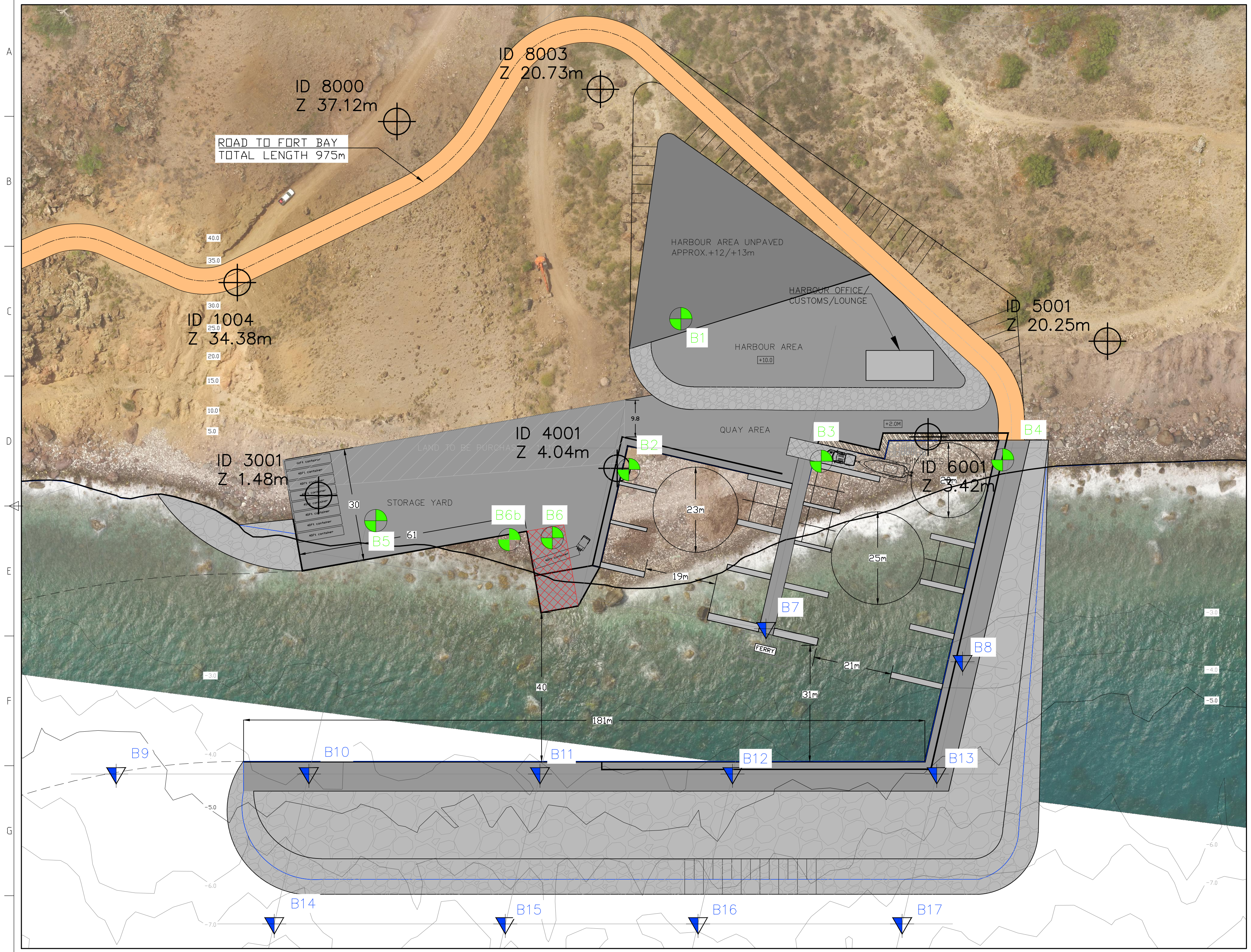
The USGS [8] does not provide a specific PGA for Saba, however islands in direct vicinity are assigned category 1.6-3.2 m/sec^2.

According to the Uniform Building Code (UBC 1997 [7]) the Leeward Islands are classified in Seismic zone 3, corresponding with a Seismic Zone factor Z of 0.3. The same zonation is adopted by the BES-code [2] – i.e. aardbevingszone 3.

For the purposes of the evaluation of seismic site class, we employed the definitions of Ground Types described in table 16-J-Soil Profile Types of the Uniform Building Code , dated 1997. The Code defines six categories of ground types, designated S_A through S_F.
When cohesionless soils are encountered, the UBC1997 [5] also distinguish parts of the 30 m top zone to classify the soil type. According UBC 1997, the SPT values (N_{30}) of the cohesionless soil layers in the top 30 m are necessary to determine the soil class. From the SPT measurements of reference [1] and correlated (assessed) DPL-5 measurements it is likely that the applicable Ground type / Soil Profile Type for the site can be assessed as S_D. This profile is described in the Code (UBC97) as follows: “Stiff soil with an average SPT value 15 ≤ N_{av} ≤ 50 blows / foot over the top 30 m”.

It is noted that in the “Stiff soil”, layers or lenses with loose densities are encountered. The liquefaction susceptibility and wave induced pore water pressure development of these layers / lenses are not investigated.

APPENDIX A LOCATION OF SOIL INVESTIGATION POINTS



LEGEND

- Planned Borehole
- Executed Borehole
- Benchmark

Borehole ID (blue = done)	Easting [UTM20N]	Northing [UTM20N]
B1	**474560.3**	**1947595.3**
B2	**474546.4**	**1947555.1**
B3	**474597.7**	**1947557.3**
B4	**474646.0**	**1947557.7**
B5	**474479.0**	**1947541.5**
B6	**474526.0**	**1947536.9**
B6b	**474514.6**	**1947536.4**
B7	474583.0	1947512.7
B8	474635.3	1947503.9
B9	474409.8	1947474.0
B10	474461.2	1947474.0
B11	474522.7	1947474.0
B12	474574.0	1947474.0
B13	474628.4	1947474.0
B14 (optional)	474451.9	1947434.0
B15	474513.5	1947434.0
B16	474564.8	1947434.0
B17	474619.2	1947434.0

0 25 m 50 m

BLACK ROCKS HARBOUR – BOREHOLE LAYOUT 21 Feb 2020 (incl completed BH's)

Designed by	Checked by	Approved by - date	Filename	Date	Scale
XXX	XXX	XXX - 00/00/00	XXX	00/00/00	1:1

XXX

XXX

X

Edition 0 — Sheet 1/1

APPENDIX B BOREHOLE LOGS

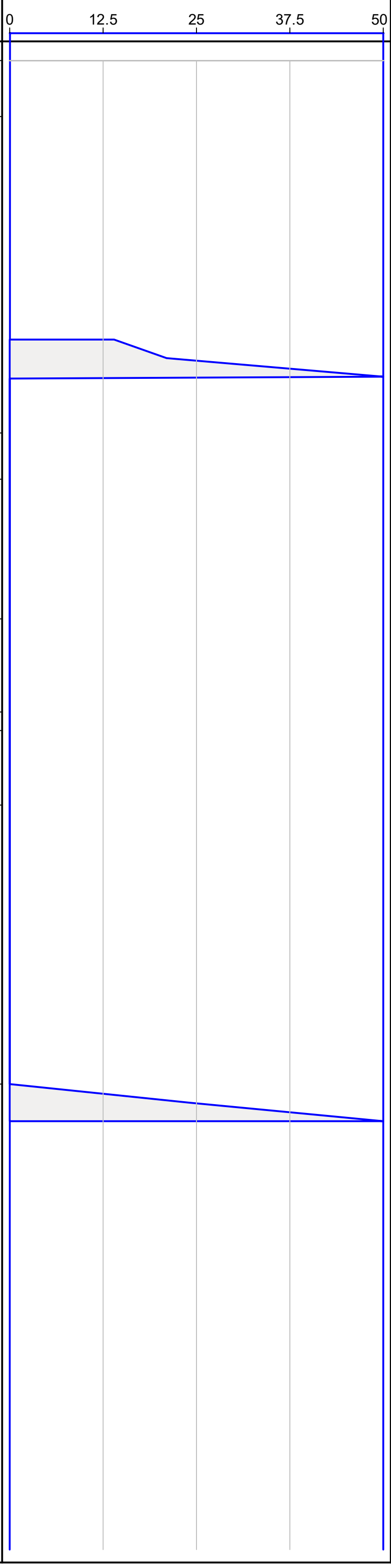
Borehole : B 01

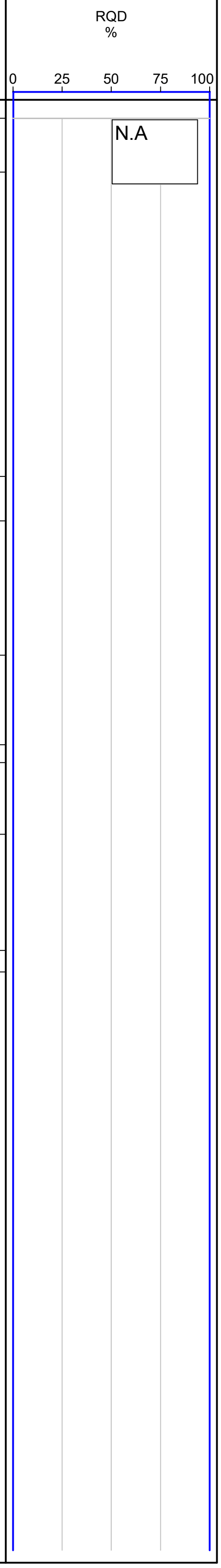
Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 13 February 2020
Completion date: 13 February 2020

Geotron International BV
2de Hogeweg
Zeist, The Netherlands

Soil description	Elevation level - NMP	Sample number	Sample Type Depth in mbgl
Surface level /Seafloor level	10.69		
Reddish brown with grey core slightly weathered andesite BOULDER	10.39	C	1 0,00-0,30
Dense dark reddish brown and grey rounded andesite GRAVEL and rounded COBBLES packed in a dark brown medium sand matrix	8.69	D	2 0,30-2,00
Reddish andesite BOULDER	8.44	C	3 2.00-2.25
Dense dark greyish brown medium SAND with some andesite subangular gravels	7.69		
Pinkish grey fresh andesite BOULDER	7.19	C	4 3,00-3,50
Loose multi colored andesite subangular gravels	7.09		
Dark purple very weathered and fractured andesite BOULDER	6.69	C	5 3,60-4.00
Multi colored angular and rounded andesite GRAVEL, PEBBLES and BOULDERS packed in a brown medium sand matrix Borehole collapses due to sand	5.19	C	6 4,65-4,77
End of drilling			





Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474560.26
: N 1947595.34
Depth sealevel till seafloor:

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

Borehole : B 02

Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 8 February 2020
Completion date: 8 February 2020

Geotron International BV
2de Hogeweg
Zeist, The Netherlands

Depth (m)	Soil description	Elevation level - NMP
0	Surface level /Seafloor level	4.01
0.00–0.30	Pinkish fresh andesite BOULDER	3.71
0.30–0.50	Grey fresh andesite BOULDER	3.51
0.50–0.70	Dense dark reddish brown and grey rounded andesite fine GRAVEL packed in a dark brown medium sand matrix	3.31
0.70–2.20	Grey fresh andesite BOULDER(S)	1.81
2.20–2.65	Dense dark greyish brown medium SAND with abundant andesite subangular gravels	1.36
2.65–3.00	Pinkish grey weathered andesite PEBBLES AND GRAVELS	1.01
3.00–7.00	Multi colored angular and subangular andesite GRAVEL, PEBBLES and BOULDERS packed in a brown medium sand matrix Corebarrel stucked due to collapsing sand	-2.99
7.00	End of drilling	

DPL 10 KG dropweight
Cone 5 cm2
(scale: 0, 12.5, 25, 37.5, 50)

Sample number	Sample Type Depht in mbgl
C	1 0,00-0,30
C	2 0,30-0.50
C	3 0,70-1,00
C	4 1,00-2,00
C	5 2,00-2,20
C	6 2,70-2,80
D	7 4,40-4,50

RQD %
(scale: 0, 25, 50, 75, 100)
N.A

Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474546.41
: N 1947555.13
Depth sealevel till seafloor:

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

Borehole : B 03

Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

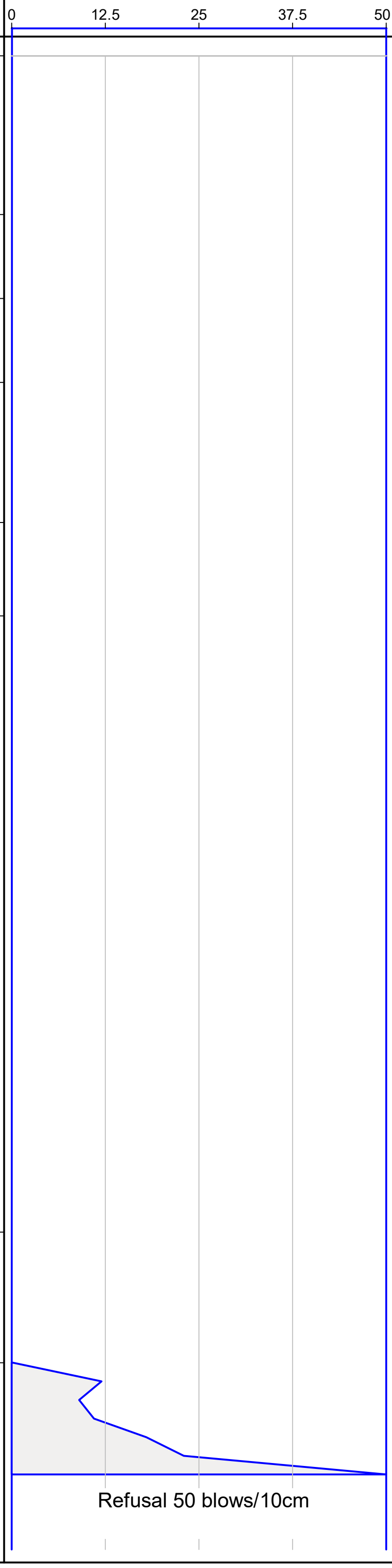
Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 11 February 2020
Completion date: 11 February 2020

Geotron International BV
2de Hogeweg
Zeist, The Netherlands

Depth	Soil description	Elevation level - NMP
0	Surface level /Seafloor level	2.13
0.00–0.85	Light grey fresh andesite BOULDER	1.28
0.85–1.30	Dense dark brown and grey rounded andesite medium to coarse GRAVEL packed in a greyish brown medium sand matrix	0.83
1.30–1.75	Grey with rusty discoloring slightly weathered andesite COBBLE and BOULDER(S)	0.38
1.75–2.50	Pinkish, reddish rounded andesite medium to coarse GRAVELS and PEBBLEs packed in a greyish brown medium sand matrix	-0.37
2.50–3.00	Grey with some reddish discoloring slightly weathered andesite BOULDER(S)	-0.87
3.00–6.30	Multi colored angular and subangular andesite GRAVEL, PEBBLES and BOULDERS packed in a light greyish brown medium sand matrix	-4.17
6.30–7.00	Brown medium angular and coarse GRAVEL with some medium sand Medium dense dark brown fine SAND with occasionaly a gravel and pebble Borehole terminiated due to collapsing sand	-4.87
7.00	End of drilling	

DPL 10 KG dropweight

Cone 5 cm2



Sample number	Sample Type Depht in mbgl
C	1 0,00-1,00
C	2 1,30-1,40
C	3 1,40-1,60
C	4 1,60-1,80
C	5 2,50-2,70
C	6 2,70-2,90
C	7 4,35-4,45
D	8 6,20-7,00

RQD %: N.A

Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474597.66
: N 1947557.33
Depth sealevel till seafloor:

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

Borehole : B 04

Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 11 February 2020
Completion date: 11 February 2020

Geotron International BV
2de Hogeweg
Zeist, The Netherlands

Depth (m)	Soil description	Elevation level - NMP	Sample Type	Sample number / Depth in mbgl
0	Surface level /Seafloor level	1.18		
0.00–1.00	Grey with some rusty discoloring fresh andesite BOULDER	0.18	C	1 0,00-1,00
1.00–1.20	Reddish brown and grey rounded andesite medium to coarse GRAVEL and PEBBLE	-0.02	C	2 1,00-1,10
1.20–1.50	Red weathered andesite BOULDER	-0.32	C	3 1,20-1,50
1.50–2.55	Multi colored andesite GRAVEL and PEBBLES with occasionaly a cobble	-1.37	C	4 2,15-2,25
2.55–2.90	Grey and pinkfresh andesite BOULDER	-1.72	C	5 2,55-2,85
2.90–3.50	Multicolor angular and rounded coarse andesite GRAVEL and PEBBLES with occasionaly a cobble	-2.32		
3.50–7.30	Multi colored angular and subangular andesite GRAVEL, PEBBLES and BOULDERS packed in a brown medium sand matrix	-6.12	C	6 4,30-4,40
7.30–7.70	Grey fresh fractured andesite BOULDER(S)	-6.52	C	7 7,40-7,70
7.70–8.30	Reddish very weathered andesite BOULDER	-7.12		
8.30–8.65	Dark grey weathered andesite BOULDER	-7.47	C	8 8,30-8,60
8.65–8.85	Grey fresh andesite COBBLES	-7.67	C	9 8,60-8,85
8.85–9.35	Dark grey medium andesite angular GRAVEL	-8.17		
9.35–9.50	Greyish red fresh andesite COBBLE	-8.32	C	10 9,35-9,50
	End of drilling			

DPL 10 KG dropweight
Cone 5 cm2
(scale: 0, 12.5, 25, 37.5, 50)

RQD %
(scale: 0, 25, 50, 75, 100)
N.A

Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474646.00
: N 1947557.72
Depth sealevel till seafloor:

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

Borehole : B 05

Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 9 February 2020
Completion date: 9 February 2020

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2de Hogeweg
Zeist, The Netherlands

DPL 10 KG dropweight — Cone 5 cm2 (scale 0 – 12.5 – 25 – 37.5 – 50)

RQD % (scale 0 – 25 – 50 – 75 – 100): N.A

Depth (m)	Elevation level - NMP	Soil description	Sample number	Sample Type Depht in mbgl
0	1.13	Surface level /Seafloor level		
0 – 1.07	0.06	Grey with some rusty discoloring fresh andesite BOULDER	C	1 0,00-1,00
1.07 – 2.05	-0.92	Dense dark reddish brown and grey rounded andesite medium to coarse GRAVEL packed in a greyish brown medium sand matrix		
2.05 – 2.40	-1.27	Dark reddish brown very weathered andesite BOULDER	C	2 2,10-2,40
2.40 – 2.60	-1.47	Pinkish fresh fractured BOULDER		
2.60 – 3.00	-1.87	Grey fresh andesite BOULDER	C	3 2,60-3,00
3.00 – 4.00	-2.87	Pinkish grey angular and rounded fine to coarse andesite GRAVEL and PEBBLES with a little medium sand	C	4 3,60-3,70
4.00 – 5.65	-4.52	Grey fresh fractured andesite BOULDER(S)	C	5 4,00-5,50
5.65 – 6.55	-5.42	Multi colored angular and subangular andesite GRAVEL, PEBBLES and BOULDERS packed in a brown medium sand matrix		
6.55 – 7.00	-5.87	Reddish brown very weathered andesite BOULDER	C	6 6,65-7,00
7.00 – 7.50	-6.37	Brown medium angular and coarse GRAVEL with some medium sand Corebarrel stucked due to collapsing sand		
7.50		End of drilling		

Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474478.99
: N 1947541.53
Depth sealevel till seafloor:

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

Borehole : B 06

Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

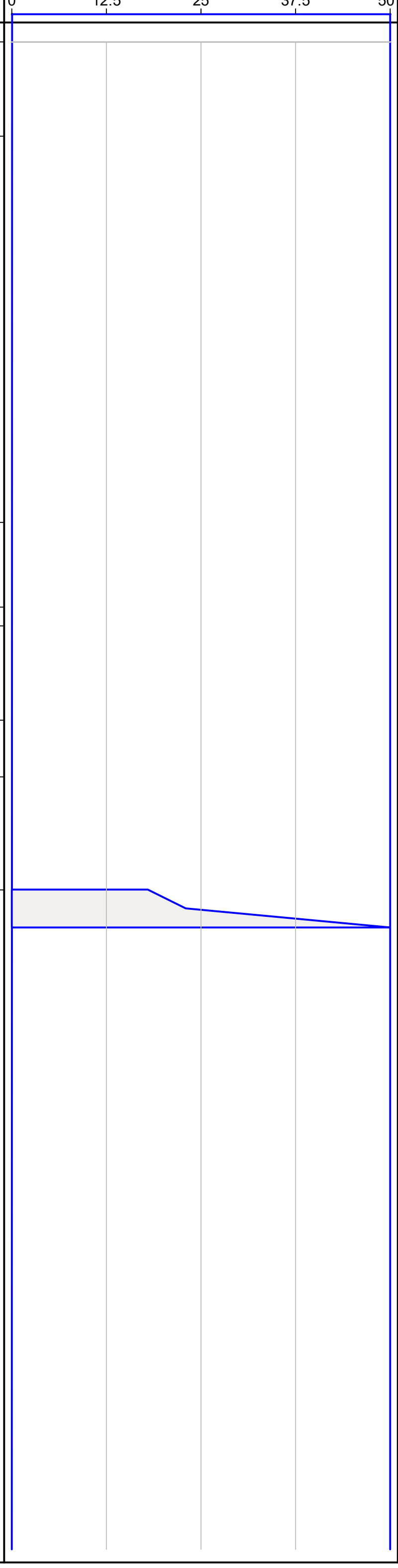
Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 10 February 2020
Completion date: 10 February 2020

Geotron International BV
2de Hogeweg
Zeist, The Netherlands

Depth	Soil description	Elevation level - NMP
0	Surface level /Seafloor level	1.58
0 – 0.50	Dark reddish brown slightly weathered andesite BOULDER	1.08
0.50 – 2.55	Dense multi colored rounded and subangular andesite GRAVEL and rounded COBBLES packed in a greyish brown medium sand matrix	-0.97
2.55 – 3.00	Dark grey fresh andesite BOULDER	-1.42
3.00 – 3.10	Loose multi colored andesite subangular gravels	-1.52
3.10 – 3.60	Dark geyish with rusty discoloring slightly weathered andesite BOULDER	-2.02
3.60 – 3.90	Grey till dark grey fresh andesite COBBLES	-2.32
3.90 – 4.50	Dense light brownish grey gravelly medium SAND with occasionally a pebble Borehole collapse after reaching sand	-2.92
	End of drilling	

DPL 10 KG dropweight

Cone 5 cm2



Sample number	Sample Type	Depht in mbgl
C	1	0,00-0,50
C	2	0,50-0,65
	3	0,70-0,75
C	5	1,80-1,90
C	6	2,10-2,20
C	7	2,55-2,65
C	8	2,65-3,00
C	4	1,55-1,65
C	9	3,10-3,50
C	10	3,65-3,80

RQD %

0 25 50 75 100

N.A

Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474526.02
: N 1947536.92
Depth sealevel till seafloor:

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

Borehole : B 07

Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 08 September 2020
Completion date: 08 September 2020

Geotron International BV
2de Hogeweg
Zeist, The Netherlands

DPL 10 KG dropweight
Cone 5 cm2
(scale: 0, 12.5, 25, 37.5, 50)

RQD %
(scale: 0, 25, 50, 75, 100)
N.A

Depth	Soil description	Elevation level - NMP
0	Surface level /Seafloor level	-3.00
0.00–0.50	Pinkish red slightly weathered andesite BOULDER	-3.50
0.50–0.90	Greyish off white with reddish spots conglomerate of medium andesite gravels cemented in CORAL LIMESTONE	-3.90
0.90–2.00	Multi coloured andesite subangular GRAVEL with some andesite pebbles	-5.00
2.00–3.00	Brownish grey very gravelly medium SAND with abundant andesite subangular gravels and andesite pebbles and cobbles	-6.00
3.00–8.00	Dense greyish brown fine to medium SAND with some andesite round gravels and cobbles Borehole collapse after 5 meter drilling in sand	-11.00
8.00	End of drilling	

Sample Type	Sample number / Depth in mbgl
C	1 0.00-0.50
C	2 0.70-0.85
C	3 0.90-1.00
C	4 1.30-1.45
C	5 1.70-1.75
D	6 2.00-3.00
C	7 2.40-2.45
D	8 3.00-4.50
C	8 3.50-3.55
C	9 4.70-4.75
D	10 4.50-6.00
C	11 6.50-6.55
D	12 6.00-7.00
D	13 7.00-8.00

Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474584
: N 1947494
Depth sealevel till seafloor: 3.0 m

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

Borehole : B 08

Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 07 September 2020
Completion date: 07 September 2020

Geotron International BV
2de Hogeweg
Zeist, The Netherlands

Depth	Soil description	Elevation level - NMP	Sample number	Sample Type / Depht in mbgl
0	Surface level /Seafloor level	-3.50		
0.00–0.55	Brownish red slightly weathered andesite BOULDER	-4.05	C C	1 0.00-0.15 2 0.15-0.20
0.55–0.80	Greyish off white with reddish spots conglomerate of medium andesite gravels cemented in CORAL LIMESTONE	-4.30	C C	3 0.20-0.50 4 0.70-0.80
0.80–1.50	Brownish grey very gravelly medium SAND with abundant andesite subangular gravels and andesite pebbles	-5.00	C C	5 1.35-1.45 6 1.50-1.55
1.50–2.50	Brownish grey very gravelly medium SAND with some andesite pebbles	-6.00	D	7 1.50-2.50
2.50–4.00	Multi coloured andesite subangular GRAVEL with some andesite pebbles	-7.50	C C	8 2.50-2.60 9 3.40-3.45
4.00–6.00	Dense greyish brown fine to medium SAND with some andesite round gravels and cobbles Borehole collapse after 2 meter drilling in sand	-9.50	D D	10 4.00-5.00 11 5.00-6.00
6	End of drilling			

DPL 10 KG dropweight, Cone 5 cm2 (scale 0 – 12.5 – 25 – 37.5 – 50): no data

RQD % (scale 0 – 25 – 50 – 75 – 100): N.A

Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474635
: N 1947504
Depth sealevel till seafloor: 3.5 m

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

Borehole : B 09

Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 06 September 2020
Completion date: 06 September 2020

Geotron International BV
2de Hogeweg
Zeist, The Netherlands

DPL 10 KG dropweight — Cone 5 cm2 (scale 0, 12.5, 25, 37.5, 50)

RQD % (scale 0, 25, 50, 75, 100): N.A

Depth (m)	Soil description	Elevation level - NMP
0	Surface level /Seafloor level	-5.60
0.00–0.50	Brownish red slightly weathered andesite BOULDER	-6.10
0.50–2.30	Brownish grey very gravelly medium SAND with adundant coral fingers, coral gravels, andesite subangular gravels and andesite pebbles	-7.90
2.30–2.50	Well cemented off white beige fine grained slightly porous BRAIN CORAL	-8.10
2.50–3.00	Brownish grey very gravelly medium SAND with abundant coral fingers, coral gravels, andesite subangular gravels and andesite pebbles	-8.60
3.00–3.50	Grey slightly weathered and fractured andesite BOULDER	-9.10
3.50–5.00	Dense multi colored andesite pebbles, boulders and COBBLES with much subangular andesite gravels packed in a medium sandy matrix	-10.60
5.00–5.50	Dark grey slightly wheathered and fractured andesite BOULDER	-11.10
5.50–6.30	Dense greyish brown fine to medium SAND with many andesite round gravels and pebbles	-11.90
6.30–7.50	Dense greyish brown fine to medium SAND with some andesite round gravels Borehole collapse after 1.7 meter drilling in sand	-13.10
	End of drilling	

Sample number	Sample Type	Depht in mbgl
1	C	0.00-0.55
2	D	1.00-1.50
3	C	2.00-2.05
4	C	2.35-2.50
4	C	3.00-3.05
5	C	3.10-3.40
6	C	3.50-3.55
7	C	3.70-3.90
8	C	4.00-4.15
9	C	5.00-5.35
10	C	5.35-5.40
11	C	5.50-5.65
12	C	6.20-6.25
13	C	6.30-6.35
14	C	6.40-6.45
15	D	6.30-7.50

Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474407
: N 1947471
Depth sealevel till seafloor: 5.6 m

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

Borehole : B 10

Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 03 September 2020
Completion date: 06 September 2020

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Zeist, The Netherlands

DPL 10 KG dropweight — Cone 5 cm2 (scale 0, 12.5, 25, 37.5, 50)
RQD % (scale 0, 25, 50, 75, 100): N.A

Depth (m)	Soil description	Elevation level - NMP
0	Surface level /Seafloor level	-4.40
0.00–1.00	Pinkish red slightly weathered andesite BOULDER	-5.40
1.00–1.50	Poor cemented greyish beige medium grained very porous CORAL LIMESTONE with many andesite gravel en cobble intusions	-5.90
1.50–3.40	Dense multi colored andesite pebbles, boulders and COBBLES with much subangular andesite gravels packed in a medium sandy matrix	-7.80
3.40–4.00	Grey slightly weathered andesite BOULDER	-8.40
4.00–5.00	Dense multi colored andesite pebbles, boulders and COBBLES with much subangular andesite gravels packed in a medium sandy matrix	-9.40
5.00–6.00	Dense greyish brown fine to medium SAND with some andesite round gravels and pebbles	-10.40
6.00–7.00	Dense greyish brown fine to medium SAND with some andesite round gravels Borehole collapse after two meter drilling in sand	-11.40
7.00	End of drilling	

Sample Type	Sample number	Depth in mbgl
C	1	0.00-0.10
C	2	0.10-0.65
C	3	0.65-0.95
C	4	1.20-1.25
C	5	1.50-1.55
C	6	1.90-1.95
C	7	2.40-2.45
C	8	3.75-3.90
C	9	4.00-4.05
C	10	4.30-4.45
C	11	4.80-4.85
D	12	5.00-6.00
D	13	6.00-7.00

Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474463
: N 1947473
Depth sealevel till seafloor: 4.40 m

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

Borehole : B 11

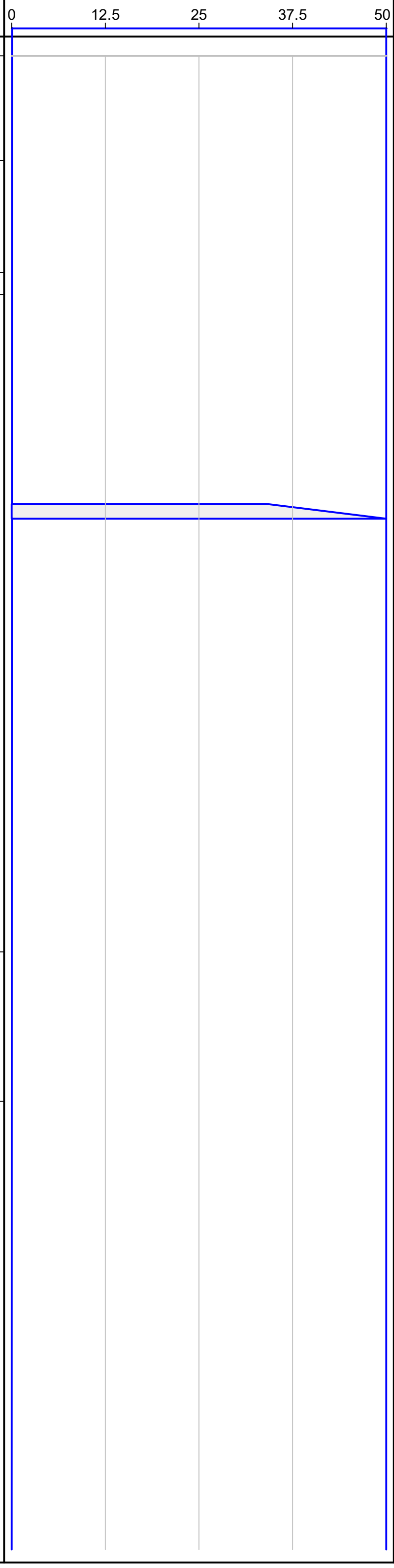
Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 03 September 2020
Completion date: 03 September 2020

Geotron International BV
2de Hogeweg
Zeist, The Netherlands

Depth	Soil description	Elevation level - NMP
0	Surface level /Seafloor level	-4.60
0.00–0.70	Reddish brown weathered andesite BOULDER	-5.30
0.70–1.45	Poor cemented greyish beige medium grained very porous CORAL LIMESTONE with some cavities filled with sand and coral fingers	-6.05
1.45–1.60	Well cemented off white fine grained slightly porous BRAIN CORAL	-6.20
1.60–6.00	Dense multi colored andesite pebbles, boulders and COBBLES with much subangular andesite gravels packed in a medium sandy matrix	-10.60
6.00–7.00	Dense greyish brown fine to medium SAND with some andesite gravel Borehole collapse after one meter drilling in sand	-11.60
7.00	End of drilling	

DPL 10 KG dropweight
Cone 5 cm2



Sample number	Sample Type Depht in mbgl
C	1 0.00-0.70
D	2 0.70-1.10
C	3 1.45-1.60
C	4 1.90-1.95
C	5 2.30-2.35
C	6 2.40-2.50
C	7 2.50-2.55
C	8 2.60-2.65
C	9 4.15-4.30
C	10 5.00-5.05
C	11 5.25-5.40
C	12 5.50-5.60
C	13 5.70-5.75
C	14 5.8-5.85
C	15 5.90-6.00
D	16 6.00-7.00

RQD %: 0 25 50 75 100 — N.A

Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474524
: N 1947471
Depth sealevel till seafloor: 4.60 m

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

Borehole : B 12

Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 31 August 2020
Completion date: 31 August 2020

Geotron International BV
2de Hogeweg
Zeist, The Netherlands

DPL 10 KG dropweight — Cone 5 cm2 (scale 0 – 12.5 – 25 – 37.5 – 50)

RQD % (scale 0 – 25 – 50 – 75 – 100): N.A

Depth	Soil description	Elevation level - NMP
0	Surface level /Seafloor level	-5.30
	Grey slightly weathered and fractures andesite BOULDER	-5.80
	Medium to poor cemented medium grained very porous CORAL LIMESTONE with much brain coral intrusion	-6.80
	Grey very gravelly medium SAND with much coral gravel and fingers and some andasite pebbles and cobbles	-8.00
	Dark reddish brown fresh andesite BOULDER	-8.30
	Loose multi colored andesite subangular GRAVEL pebbles and cobbles packed in a medium sandy matrix	-12.30
	Dense reddish brown fine to medium SAND with some andesite gravel Borehole collapse after one meter drilling in sand	-13.30
8	End of drilling	

Sample number	Sample Type Depht in mbgl
C	1 0.00-0.25
C	2 0.35-0.40
C	3 0.40-0.50
C	4 0.95-1.00
C	5 1.00-1.05
C	6 1.15-1.30
C	7 2.05-2.15
C	8 2.30-2.40
C	9 2.70-3.00
D	10 3.00-5.00
C	11 6.00-6.05
C	12 6.60-6.65
D	13 7.00-8.00

Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474578
: N 1947474
Depth sealevel till seafloor: - 4.50 m

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

Borehole : B 13

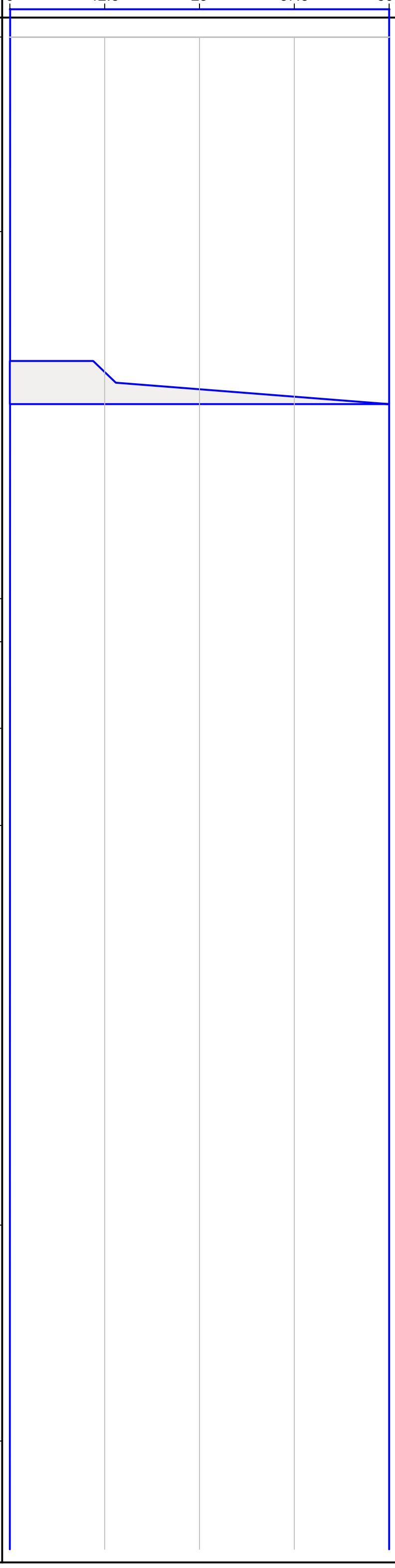
Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 28 August 2020
Completion date: 28 August 2020

Geotron International BV
2de Hogeweg
Zeist, The Netherlands

Depth	Soil description	Elevation level - NMP
0	Surface level /Seafloor level	-5.30
0 – 0.90	Dark reddish brown slightly weathered andesite BOULDER	-6.20
0.90 – 2.60	Grey very gravelly medium SAND with much coral gravel and fingers and some andasite pebbles and cobbles	-7.90
2.60 – 2.80	Dark grey fresh andesite BOULDER with coral growed on each side of the core	-8.10
2.80 – 3.20	Loose multi colored andesite subangular GRAVEL	-8.50
3.20 – 3.65	Dark geyish with rusty discoloring slightly weathered andesite BOULDER	-8.95
3.65 – 5.50	Dense light brownish grey gravelly medium SAND with many andesite pebbles and cobbles	-10.80
5.50 – 6.50	Dense brown gravelly SAND with many andesite pebbles and cobbles Borehole collapse after reaching sand	-11.80
6.50	End of drilling	

DPL 10 KG dropweight
Cone 5 cm2



Sample Type	Sample number	Depht in mbgl
C	1	0,00-0,20
C	2	0,20-0,75
C	3	0,75-0,95
C	4	1,50-1,60
C	5	1,65-1,70
C	6	2,60-2,80
C	7	3,20-3,35
C	8	3,40-3,50
C	9	3,55-3,65
C	10	4,45-4,50
C	11	4,50-4,60
C	12	5,20-5,30
C	13	5,40-5,45
D	14	5,50-6,50

RQD %: N.A

Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474622
: N 1947472
Depth sealevel till seafloor: - 5.30 m

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

Borehole : B 15

Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

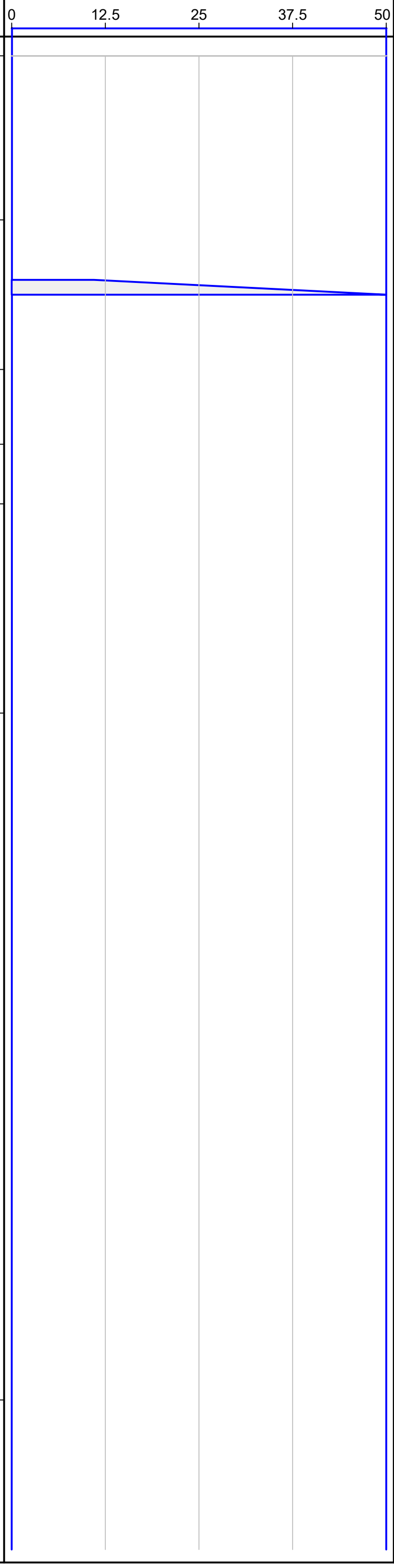
Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 27 August 2020
Completion date: 27 August 2020

Geotron International BV
2de Hogeweg
Zeist, The Netherlands

Soil description	Elevation level - NMP
Surface level /Seafloor level	-6.80
Medium to poor cemented medium grained very porous and cavernous CORAL LIMESTONE with abundant shell and coral intrusions	-7.90
Greyish beige gravelly medium to coarse SAND	-8.90
Poor to medium cemented grey coarse grained very porous CORAL LIMESTONE	-9.40
Well cemented off white fine grained slightly porous BRAIN CORAL	-9.80
Off white beige very sandy coral GRAVEL and coral fingers	-11.20
Multi coloured andesite gravel, pebbles and boulders packed in a brown medium SAND matrix	-15.80
End of drilling	

DPL 10 KG dropweight

Cone 5 cm2



Sample number	Sample Type Depht in mbgl
C	1 0.00-0.15
C	2 0.25-0.30
D	3 1.10-2.10
C	4 2.50-2.55
C	5 2.60-2.70
C	6 2.70-2.85
C	7 2.90-2.95
C	8 4.40-4.60
C	9 5.60-5.70
C	10 6.40-6.45
C	11 6.70-6.75
C	12 7.00-7.05
C	13 7.30-7.35
C	14 7.50-7.60
C	15 8.00-8.15
C	16 8.25-8.30
C	17 8.40-8.50
D	18 4.40-8.20

RQD %: N.A

Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474509
: N 1947432
Depth sealevel till seafloor: - 6.80 m

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

Borehole : B 16

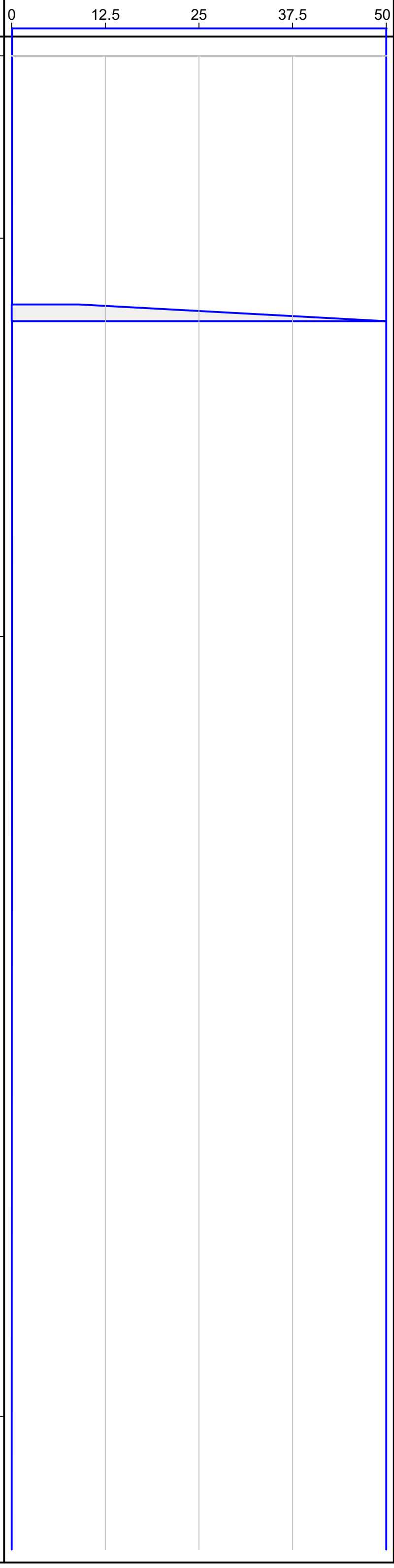
Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 26 August 2020
Completion date: 26 August 2020

Geotron International BV
2de Hogeweg
Zeist, The Netherlands

Depth (m)	Soil description	Elevation level - NMP
0	Surface level /Seafloor level	7.00
0.00–1.10	Medium to poor cemented medium grained very porous and cavernous CORAL LIMESTONE	5.90
1.10–3.50	Greyish beige very gravelly medium to coarse SAND with much coral gravel. pebbles and fingers, and rare andesite gravels	3.50
3.50–8.20	Dense light reddish brownish gravelly medium SAND with many andesite pebbles and cobbles	-1.20
8.20	End of drilling	

DPL 10 KG dropweight
Cone 5 cm2



Sample number	Sample Type	Depth in mbgl
1	C	0.00-0.05
2	C	0.25-0.40
3	C	0.40-0.55
4	C	0.60-0.65
5	C	0.70-0.80
6	C	0.90-1.00
7	C	1.00-1.05
8	D	1.10-3.50
9	C	2.90-3.00
10	C	3.70-3.75
11	C	3.80-3.85
12	C	4.20-4.35
13	C	4.70-4.80
14	C	5.25-5.35
15	C	5.45-5.55
16	C	5.70-5.80
17	C	7.30-7.35
18	C	7.50-7.55
19	D	3.50-8.20

RQD %: N.A

Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474560
: N 1947428
Depth sealevel till seafloor: - 7.00 m

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

Borehole : B 17

Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 25 August 2020
Completion date: 25 August 2020

Geotron International BV
2de Hogeweg
Zeist, The Netherlands

DPL 10 KG dropweight — Cone 5 cm2 (scale 0, 12.5, 25, 37.5, 50)

RQD % (scale 0, 25, 50, 75, 100): N.A

Soil description	Elevation level - NMP
Surface level /Seafloor level	-7.60
Greyish off white with reddish spots conglomerate of medium andesite gravels cemented in CORAL LIMESTONE with much brain coral intrusions	-8.35
Medium cemented greyish beige medium to coarse grained very porous CORAL LIMESTONE	-9.50
Well cemented off white fine grained slightly porous BRAIN CORAL	-10.00
Off white beige very gravelly medium SAND and coral fingers	-10.25
Greyish off white with reddish spots conglomerate of medium andesite gravels cemented in CORAL LIMESTONE with abundant brain coral pieces	-11.85
Multi coloured andesite gravel, pebbles and boulders packed in a brown medium SAND matrix	-15.10
End of drilling	

Sample number	Sample Type / Depht in mbgl
C	1 0.00-0.25
C	2 0.35-0.45
C	3 0.50-0.70
C	4 0.70-0.90
C	5 1.75-1.90
C	6 2.00-2.35
C	7 2.90-2.95
C	8 3.00-3.40
C	9 3.70-3.85
C	10 3.85-3.95
C	11 4.00-4.10
C	12 4.50-4.60
C	13 5.40-5.45
C	14 5.70-5.75
C	15 7.10-7.25

Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474622
: N 1947430
Depth sealevel till seafloor: -7.60 m

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

Borehole : B 06 B

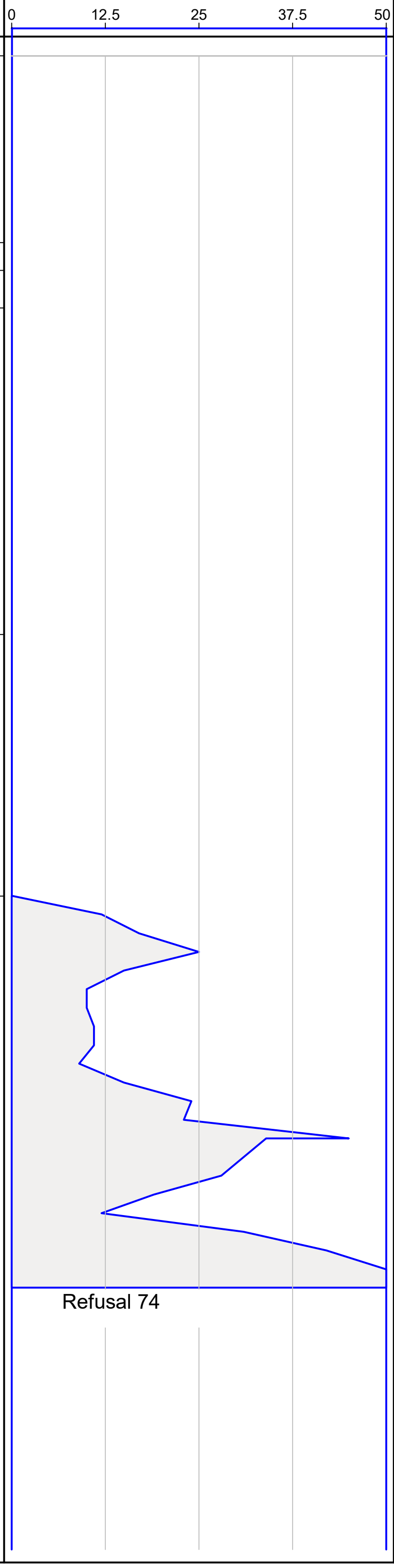
Project No: P 20001
Project: Black Rock Harbour
Principal: Public Entity Saba
Location: Saba

Drilling Engineer: ALa/RJa
Logged by: ALa
Start date: 12 February 2020
Completion date: 12 February 2020

Geotron International BV
2de Hogeweg
Zeist, The Netherlands

Depth	Soil description	Elevation level - NMP
0	Surface level /Seafloor level	1.49
0 – 0.49 (approx.)	Pinkish grey slightly weathered andesite BOULDER	0.49
	Pinkish red fresh andesite COBBLE	0.34
	Grey fresh andesite COBBLE	0.14
	Loose multi colored andesite subangular gravels packed in medium sandy matrix	-1.61
	Dense light brownish grey gravelly medium SAND Borehole collapse after reaching sand	-3.01
	End of drilling	

DPL 10 KG dropweight
Cone 5 cm2



Sample number	Sample Type Depth in mbgl
C	1 0,00-0,50
C	2 1,00-1,12
C	3 1,15-1,30

RQD %: 0 25 50 75 100 — N.A

Drilling method: Rotary coring BQTK
Casing depth: Till end depth
Diameter borehole: 53 mm
Groundwater level: N.D.

Diameter core: 40 mm
Coordinates: E 474514.55
: N 1947536.44
Depth sealevel till seafloor:

C = Core sample
U = Undisturbed sample
D = Disturbed sample
B = Bulk sample

APPENDIX C PHOTOGRAPHS CORE RUNS

Blackrock port SABA	
Client:	Pubilc Entity Saba
Contractor:	GEOTRON INTERNATIONAL
Location:	Saba
Contract:	GIO 20001

Pictures Core recovery's BH 01

0
1
2
3
4
5
6

	Blackrock port SABA	
	Client:	Pubilc Entity Saba
	Contractor:	GEOTRON INTERNATIONAL
	Location:	Saba
	Contract:	GIO 20001
Pictures Core recovery's BH 02		

0
1
2
3
4
5
6

Blackrock port SABA

Client:	Pubilc Entity Saba
Contractor:	GEOTRON INTERNATIONAL
Location:	Saba
Contract:	GIO 20001

Pictures Core recovery's BH 03

0
1
2
3
4
5
6

	Blackrock port SABA	
	Client:	Pubilc Entity Saba
	Contractor:	GEOTRON INTERNATIONAL
	Location:	Saba
	Contract:	GIO 20001
Pictures Core recovery's BH 04		

0
1
2
3
4
5
6
7
8
9

	Blackrock port SABA	
	Client:	Pubilc Entity Saba
	Contractor:	GEOTRON INTERNATIONAL
	Location:	Saba
	Contract:	GIO 20001

Pictures Core recovery's BH 05

0
1
2
3
4
5
6
7

Blackrock port SABA

Client:	Pubilc Entity Saba
Contractor:	GEOTRON INTERNATIONAL
Location:	Saba
Contract:	GIO 20001

Pictures Core recovery's BH 06

0
1
2
3
4
5
6

Blackrock port SABA

Client:	Pubilc Entity Saba
Contractor:	GEOTRON INTERNATIONAL
Location:	Saba
Contract:	GIO 20001

Pictures Core recovery's BH 06 B

0
1
2
3
4
5
6

Blackrock port SABA

Client:	Pubilc Entity Saba
Contractor:	GEOTRON INTERNATIONAL
Location:	Saba
Contract:	GIO 20001

Pictures Core recovery's BH 7

0
1
2
3
4
5
6

Blackrock port SABA	
Client:	Pubilc Entity Saba
Contractor:	GEOTRON INTERNATIONAL
Location:	Saba
Contract:	GIO 20001

Pictures Core recovery's BH 8

0
1
2
3
4
5
6

	Blackrock port SABA	
	Client:	Pubilc Entity Saba
	Contractor:	GEOTRON INTERNATIONAL
	Location:	Saba
	Contract:	GIO 20001
Pictures Core recovery's BH 9		

0
1
2
3
4
5
6

Blackrock port SABA

Client:	Pubilc Entity Saba
Contractor:	GEOTRON INTERNATIONAL
Location:	Saba
Contract:	GIO 20001

Pictures Core recovery's BH 10

0

1

2

3

4

5

6

	Blackrock port SABA	
	Client:	Pubilc Entity Saba
	Contractor:	GEOTRON INTERNATIONAL
	Location:	Saba
	Contract:	GIO 20001

Pictures Core recovery's BH 11

0
1
2
3
4
5
6

Blackrock port SABA	
Client:	Pubilc Entity Saba
Contractor:	GEOTRON INTERNATIONAL
Location:	Saba
Contract:	GIO 20001

Pictures Core recovery's BH 12

0
1
2
3
4
5
6
7

Blackrock port SABA

Client:	Pubilc Entity Saba
Contractor:	GEOTRON INTERNATIONAL
Location:	Saba
Contract:	GIO 20001

Pictures Core recovery's BH 13

0
1
2
3
4
5
6

Blackrock port SABA

Client:	Pubilc Entity Saba
Contractor:	GEOTRON INTERNATIONAL
Location:	Saba
Contract:	GIO 20001

Pictures Core recovery's BH 15

0
1
2
3
4
5
6
7
8

Blackrock port SABA

Client:	Pubilc Entity Saba
Contractor:	GEOTRON INTERNATIONAL
Location:	Saba
Contract:	GIO 20001

Pictures Core recovery's BH 16

0
1
2
3
4
5
6
7
8

Blackrock port SABA	
Client:	Pubilc Entity Saba
Contractor:	GEOTRON INTERNATIONAL
Location:	Saba
Contract:	GIO 20001

Pictures Core recovery's BH 17

0
1
2
3
4
5
6
7

APPENDIX D LABORATORY RESULTS – SAND AND GRAVEL

BS1377: Part 2:1990 / BS EN ISO 17892-3 : 2015

PARTICLE DENSITY

Location	Depth (m)	Sample Ref	Sample Type	Description	Particle Density Mg/m³	Test Method
BH1	0.30-2.00		D	Greyish brown silty gravelly fine SAND. Gravel is rock.	2.75	2
BH3	6.20-7.00		D	Dark brown silty SAND.	2.75	2
BH7	3.00-3.45		D	Dark brown SAND with rare shell fragments.	2.77	2
BH7	7.00-8.00		D	Dark brown SAND with rare very fine shell fragments.	2.75	2
BH9	6.30-7.50		D	Dark grey SAND with rare shell fragments.	2.76	2
BH10	6.00-8.00		D	Dark grey SAND with rare very fine shell fragments.	2.76	2
BH12	7.00-8.00		D	Dark brown SAND with rare very fine shell fragments.	2.75	2
BH16	3.50-8.20		D	Dark brown SAND with rare gravel and very fine shell fragments.	2.79	2
BH8	4.00-6.00	AMAL		Dark brown SAND with rare fine shell fragments.	2.74	2

Notes

Test Method
1. Gas jar : BS1377 : Part 2 : 1990 Clause 8.2
2. Pycnometer : BS EN ISO 17892-3:2015 (UKAS Accredited)

Checked and Approved by:

J Sturges - Operations Manager
15/12/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

Version 00.991230

1262 - PSD BH01 00.30 D - 32168-383439.XLSM

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

Location	BH1
Depth (m)	0.30-2.00
Sample Type	D

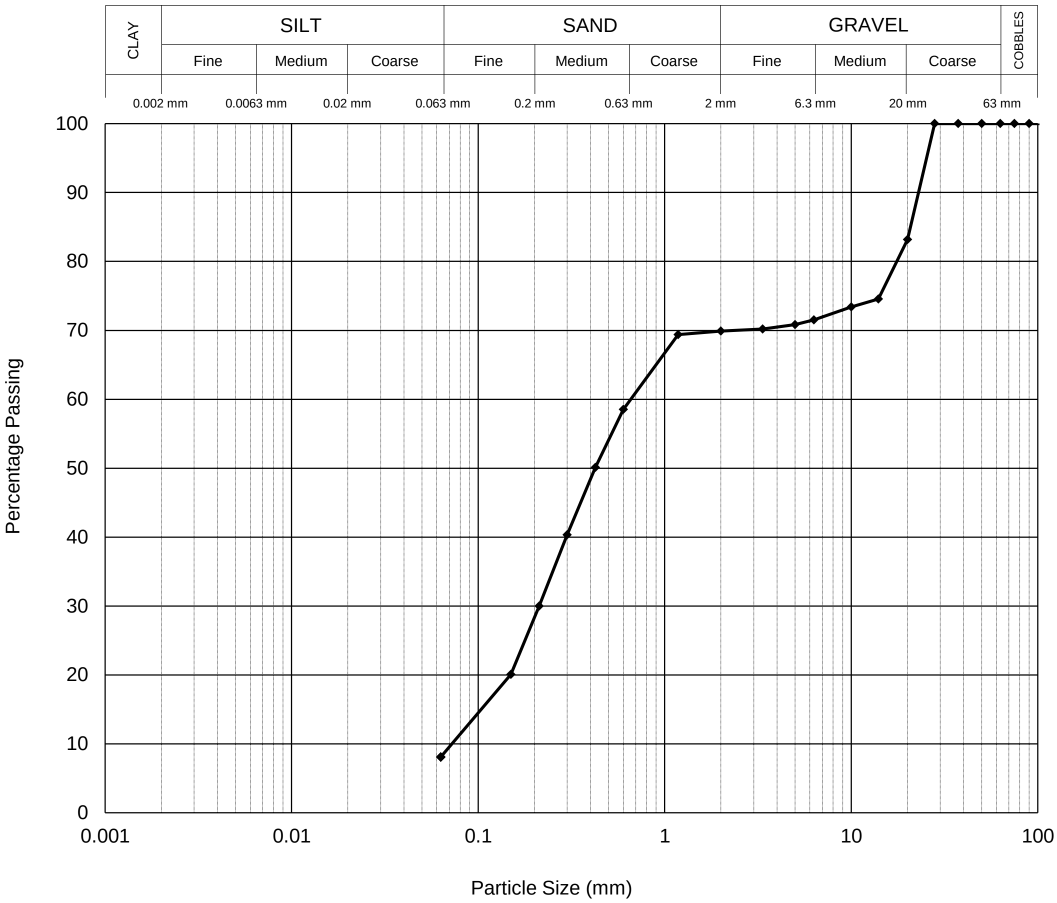
Description

Greyish brown silty gravelly fine SAND. Gravel is rock.

Remarks: Insuffcient sample supplied to comply with BS EN ISO 17892-4 : 2016 minimum mass requirements

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	83
14.0 mm	75
10.0 mm	73
6.30 mm	72
5.00 mm	71
3.35 mm	70
2.00 mm	70
1.18 mm	69
600 µm	59
425 µm	50
300 µm	40
212 µm	30
150 µm	20
63 µm	8



Particle Proportions	
Cobbles	0.0
Gravel	30.1
Sand	61.8
Silt & Clay	8.1

Processed by CC
Checked and Approved by

J Sturges - Operations Manager
15/12/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS GIO20001

Version 98.200730

1262 - PSD BH03 06.20 D - 32168-383427.XLSB

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

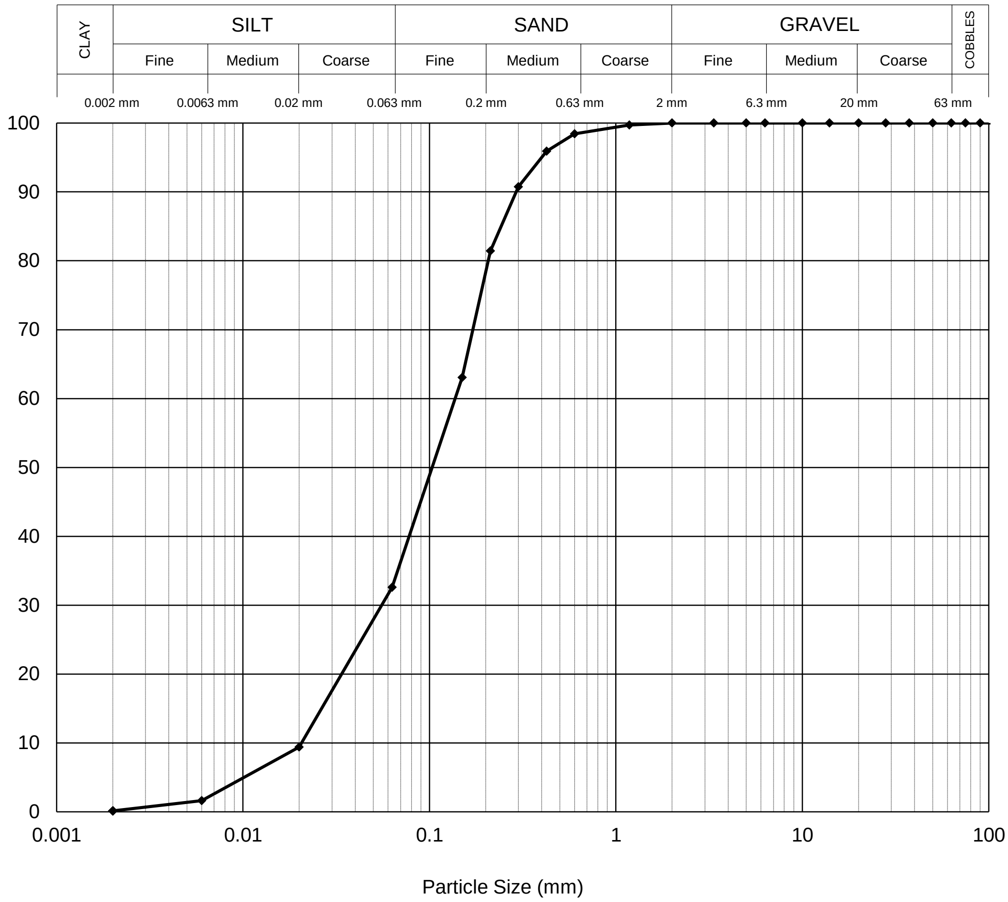
Location	BH3
Depth (m)	6.20-7.00
Sample Type	D

Description

Dark brown silty SAND.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve
BS EN ISO 17892-4 : 2016 : Clause 5.4 - Sedimentation by Pipette

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	98
425 µm	96
300 µm	91
212 µm	81
150 µm	63
63 µm	33



Sedimentation	
No Pre-treatment used	
Temp (°C)	25
Size	% Pass
20 µm	9
6 µm	2
2 µm	0
Particle Density 2.70(A) Mg/m³	

Particle Proportions	
Cobbles	0.0
Gravel	0.0
Sand	67.4
Silt	32.5
Clay	0.1

Processed by AD
Checked and Approved by

J Sturges - Operations Manager
17/12/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

GEOLABS ®
UKAS TESTING 1982

Version 98.200730

Test Report By GEOLABS Limited Bucknalls Lane, Garston, Watford, Hertfordshire, WD25 9XX

Client : Geotron Caribbean B.V, Mauritslaan 1, Willemstad Curacao, ,

(Ref 1608193919)

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

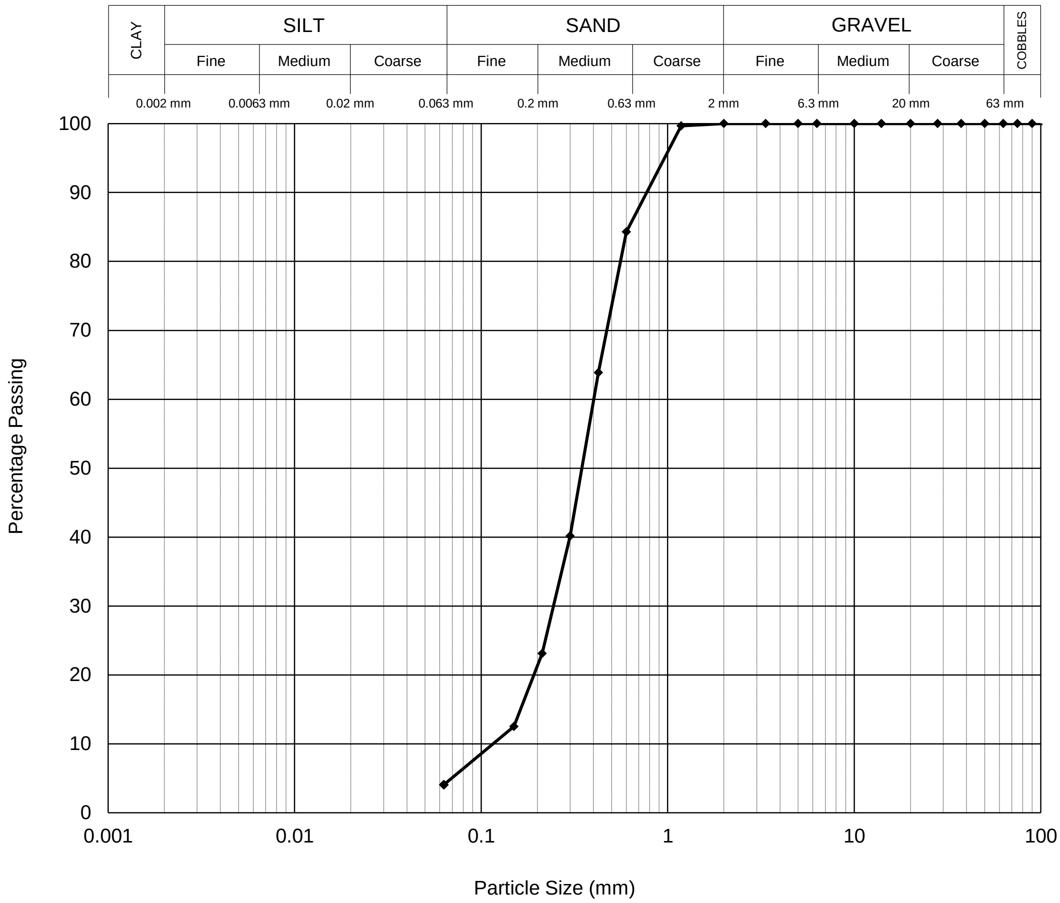
Location	BH7
Depth (m)	3.00-3.45
Sample Type	D

Description

Dark brown SAND with rare shell fragments.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	84
425 µm	64
300 µm	40
212 µm	23
150 µm	13
63 µm	4



Particle Proportions	
Cobbles	0.0
Gravel	0.0
Sand	95.9
Silt & Clay	4.1

Processed by CC
Checked and Approved by

J Sturges - Operations Manager
15/12/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

GEOLABS

1262 - PSD BH07 07.00 D - 32168-383424.XLSM

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

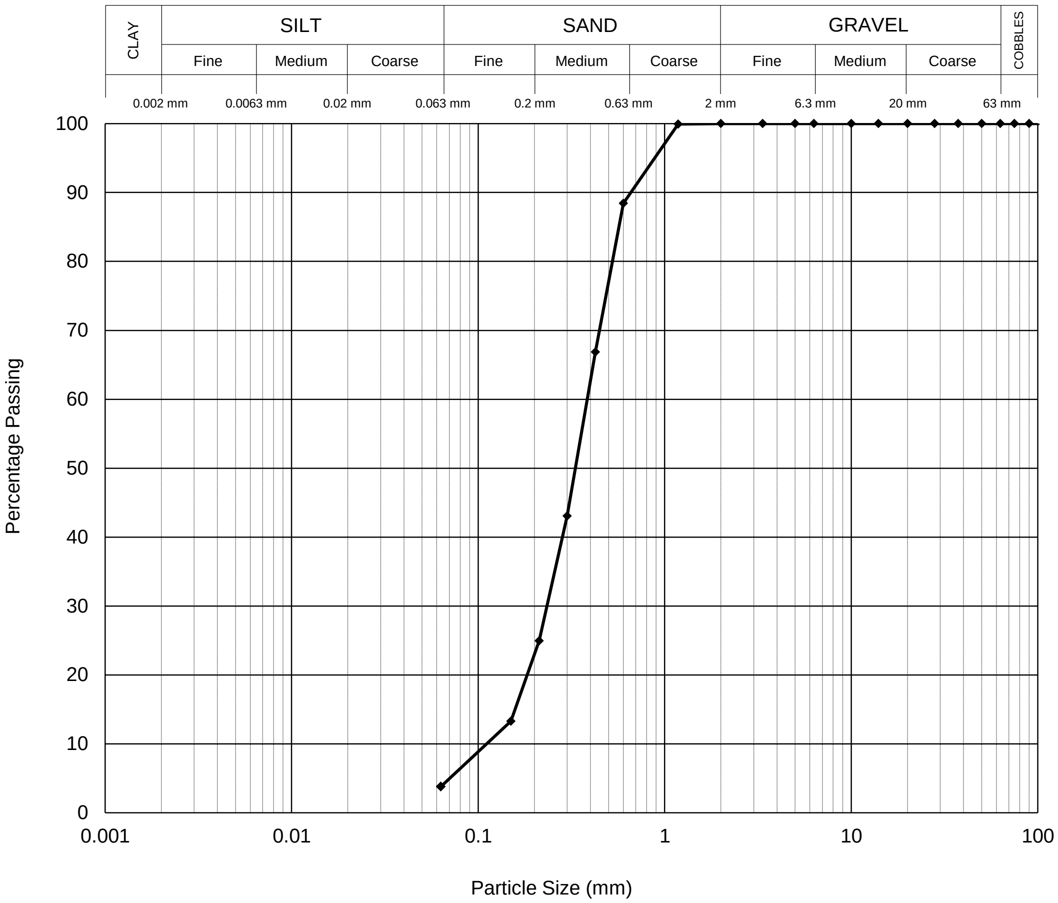
Location	BH7
Depth (m)	7.00-8.00
Sample Type	D

Description

Dark brown SAND with rare very fine shell fragments.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	88
425 µm	67
300 µm	43
212 µm	25
150 µm	13
63 µm	4



Particle Proportions	
Cobbles	0.0
Gravel	0.0
Sand	96.2
Silt & Clay	3.8

Processed by CC
Checked and Approved by

J Sturges - Operations Manager
15/12/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

GEOLABS®
UKAS TESTING 1982

Version 98.200730

1262 - PSD BH8 04.00 AMAL - 32168-505454.XLSM

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

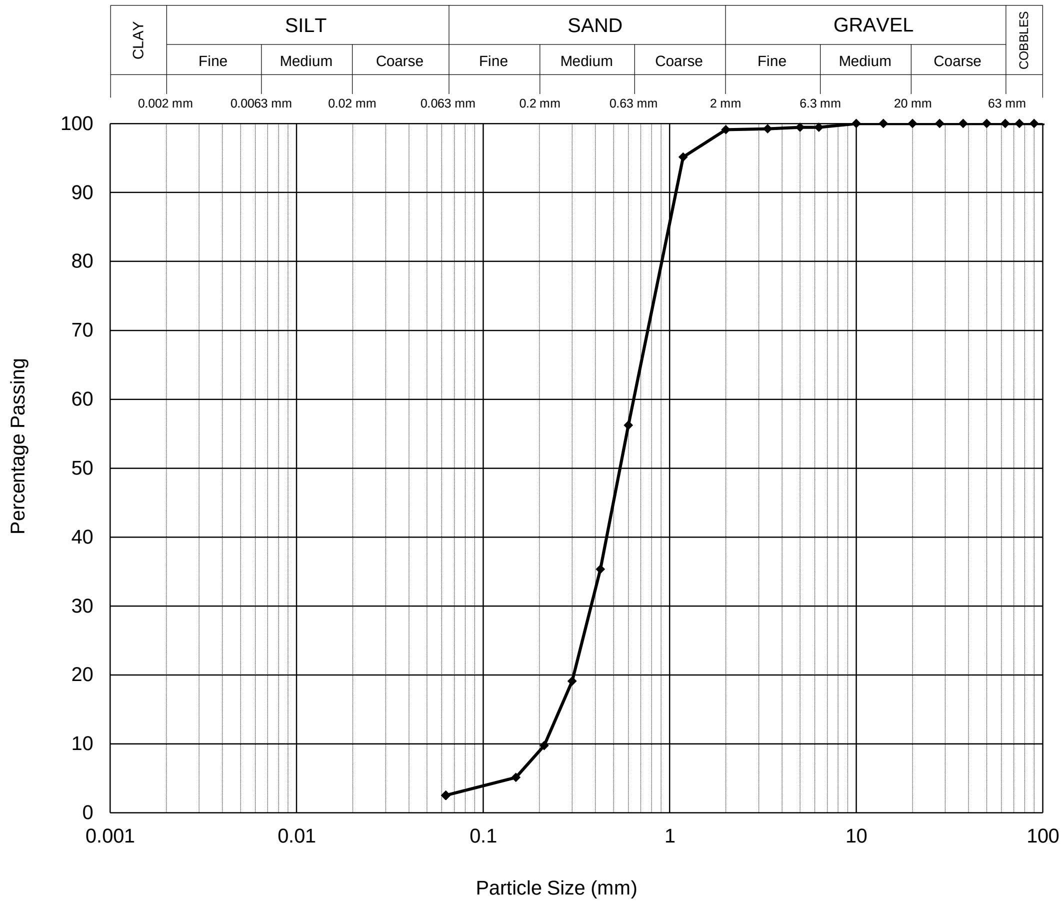
Location	BH8
Sample Ref	AMAL
Depth (m)	4.00-6.00

Description

Dark brown SAND with rare fine shell fragments.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	99
5.00 mm	99
3.35 mm	99
2.00 mm	99
1.18 mm	95
600 µm	56
425 µm	35
300 µm	19
212 µm	10
150 µm	5
63 µm	3



Particle Proportions	
Cobbles	0.0
Gravel	0.9
Sand	96.6
Silt & Clay	2.5

Version 98.200730

Processed by CC
Checked and Approved by

J Sturges - Operations Manager
15/12/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

GEOLABS®

Test Report By GEOLABS Limited Bucknalls Lane, Garston, Watford, Hertfordshire, WD25 9XX

Client : Geotron Caribbean B.V, Mauritslaan 1, Willemstad Curacao, ,

(Ref 1608026528)

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

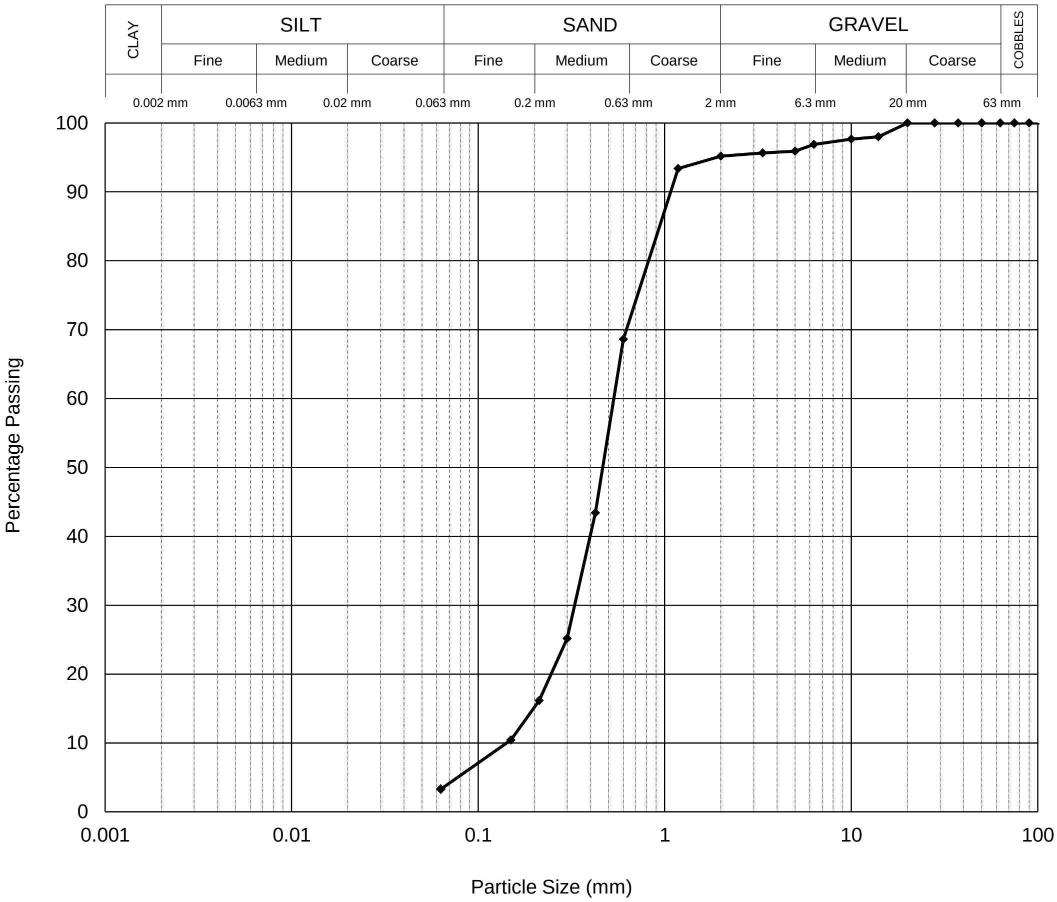
Location	BH9
Depth (m)	1.00-1.50
Sample Type	D

Description

Brownish grey slightly gravelly SAND with rare fine shell fragments.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	98
10.0 mm	98
6.30 mm	97
5.00 mm	96
3.35 mm	96
2.00 mm	95
1.18 mm	93
600 µm	69
425 µm	43
300 µm	25
212 µm	16
150 µm	10
63 µm	3



Particle Proportions	
Cobbles	0.0
Gravel	4.8
Sand	91.9
Silt & Clay	3.3

Processed by CC
Checked and Approved by

J Sturges - Operations Manager
15/12/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

Test Report By GEOLABS Limited Bucknalls Lane, Garston, Watford, Hertfordshire, WD25 9XX

Client : Geotron Caribbean B.V, Mauritslaan 1, Willemstad Curacao, ,

(Ref 1608026533)

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

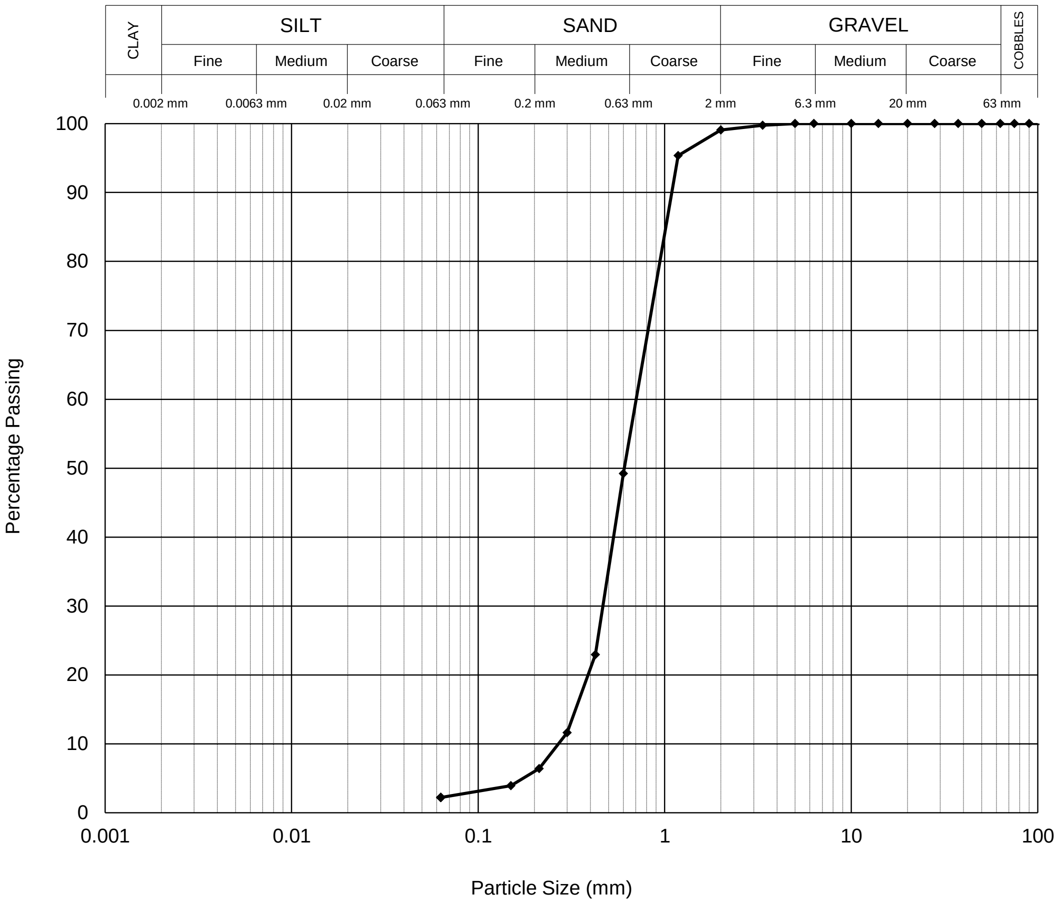
Location	BH9
Depth (m)	6.30-7.50
Sample Type	D

Description

Dark grey SAND with rare shell fragments.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	99
1.18 mm	95
600 µm	49
425 µm	23
300 µm	12
212 µm	6
150 µm	4
63 µm	2



Particle Proportions	
Cobbles	0.0
Gravel	0.9
Sand	96.8
Silt & Clay	2.3

Processed by CC
Checked and Approved by

J Sturges - Operations Manager
15/12/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

Test Report By GEOLABS Limited Bucknalls Lane, Garston, Watford, Hertfordshire, WD25 9XX

Client : Geotron Caribbean B.V, Mauritslaan 1, Willemstad Curacao, ,

(Ref 1608026538)

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

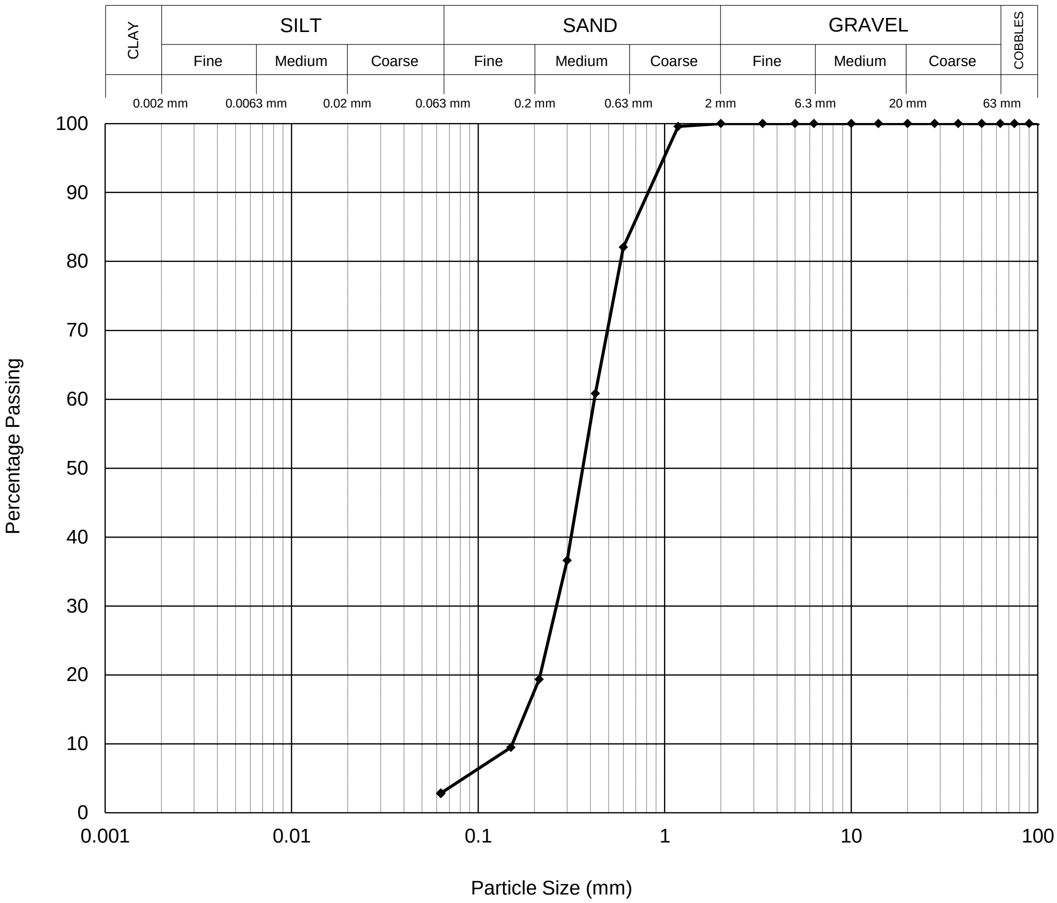
Location BH10
Depth (m) 6.00-8.00
Sample Type D

Description

Dark grey SAND with rare very fine shell fragments.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	82
425 µm	61
300 µm	37
212 µm	19
150 µm	9
63 µm	3



Particle Proportions	
Cobbles	0.0
Gravel	0.0
Sand	97.2
Silt & Clay	2.8

Processed by CC
Checked and Approved by

J Sturges - Operations Manager
15/12/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

GEOLABS® UKAS TESTING 1982

1262 - PSD BH12 03.00 D - 32168-383436.XLSM

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

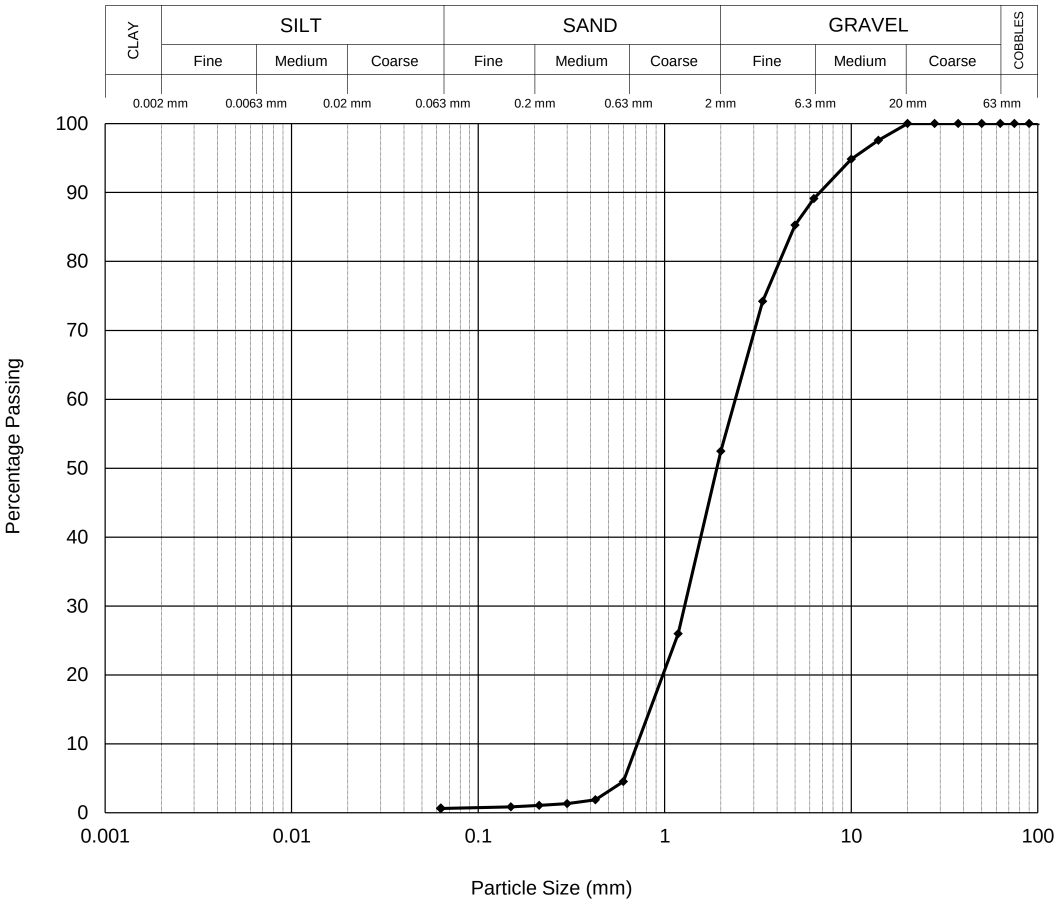
Location BH12
Depth (m) 3.00-3.50
Sample Type D

Description

Dark brown GRAVEL and SAND. Gravel and sand includes shell fragments.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	98
10.0 mm	95
6.30 mm	89
5.00 mm	85
3.35 mm	74
2.00 mm	52
1.18 mm	26
600 µm	5
425 µm	2
300 µm	1
212 µm	1
150 µm	1
63 µm	1



Particle Proportions	
Cobbles	0.0
Gravel	47.5
Sand	51.8
Silt & Clay	0.7

Version 98.200730

Processed by CC
Checked and Approved by

J Sturges - Operations Manager
15/12/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

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UKAS TESTING 1982

Test Report By GEOLABS Limited Bucknalls Lane, Garston, Watford, Hertfordshire, WD25 9XX

Client : Geotron Caribbean B.V, Mauritslaan 1, Willemstad Curacao, ,

(Ref 1608026547)

1262 - PSD BH12 07.00 D - 32168-383440.XLSM

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

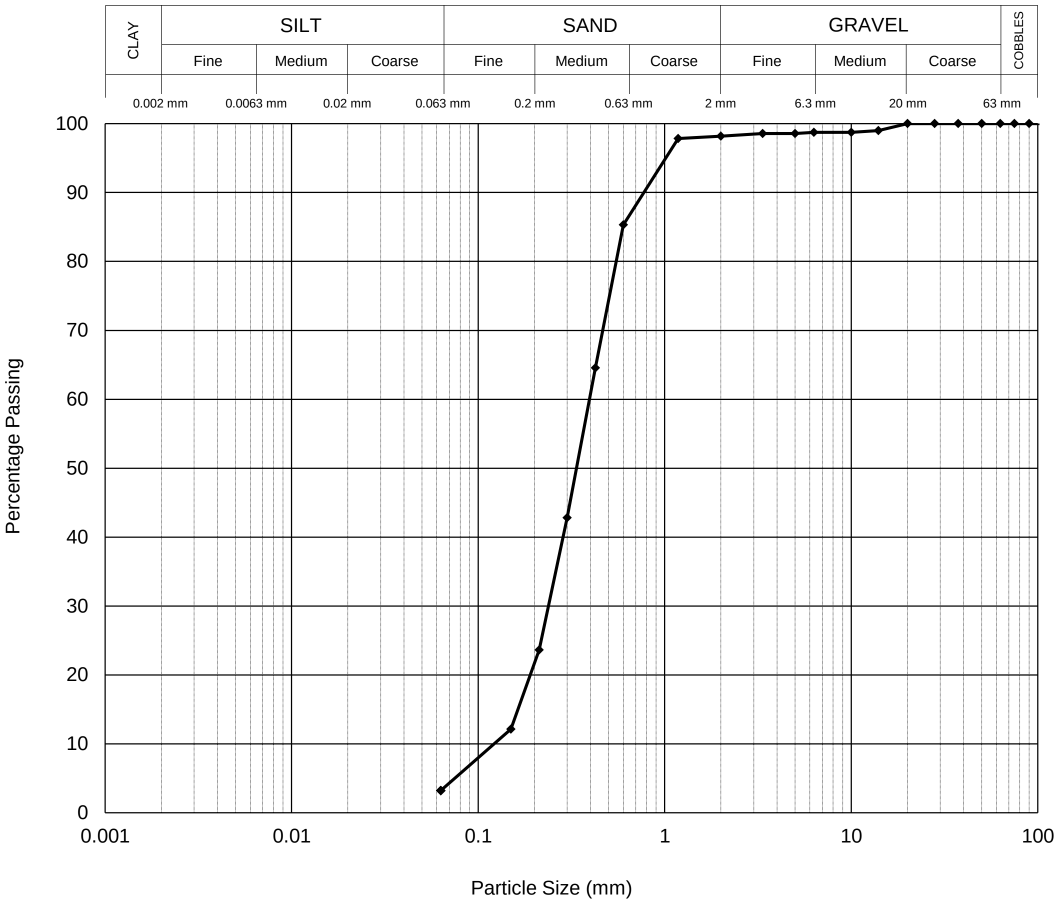
Location	BH12
Depth (m)	7.00-8.00
Sample Type	D

Description

Dark brown SAND with rare very fine shell fragments.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	99
10.0 mm	99
6.30 mm	99
5.00 mm	99
3.35 mm	99
2.00 mm	98
1.18 mm	98
600 µm	85
425 µm	65
300 µm	43
212 µm	24
150 µm	12
63 µm	3



Particle Proportions	
Cobbles	0.0
Gravel	1.8
Sand	95.0
Silt & Clay	3.2

Processed by CC
Checked and Approved by

J Sturges - Operations Manager
15/12/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

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Version 98.200730

Test Report By GEOLABS Limited Bucknalls Lane, Garston, Watford, Hertfordshire, WD25 9XX

Client : Geotron Caribbean B.V, Mauritslaan 1, Willemstad Curacao, ,

(Ref 1608026552)

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

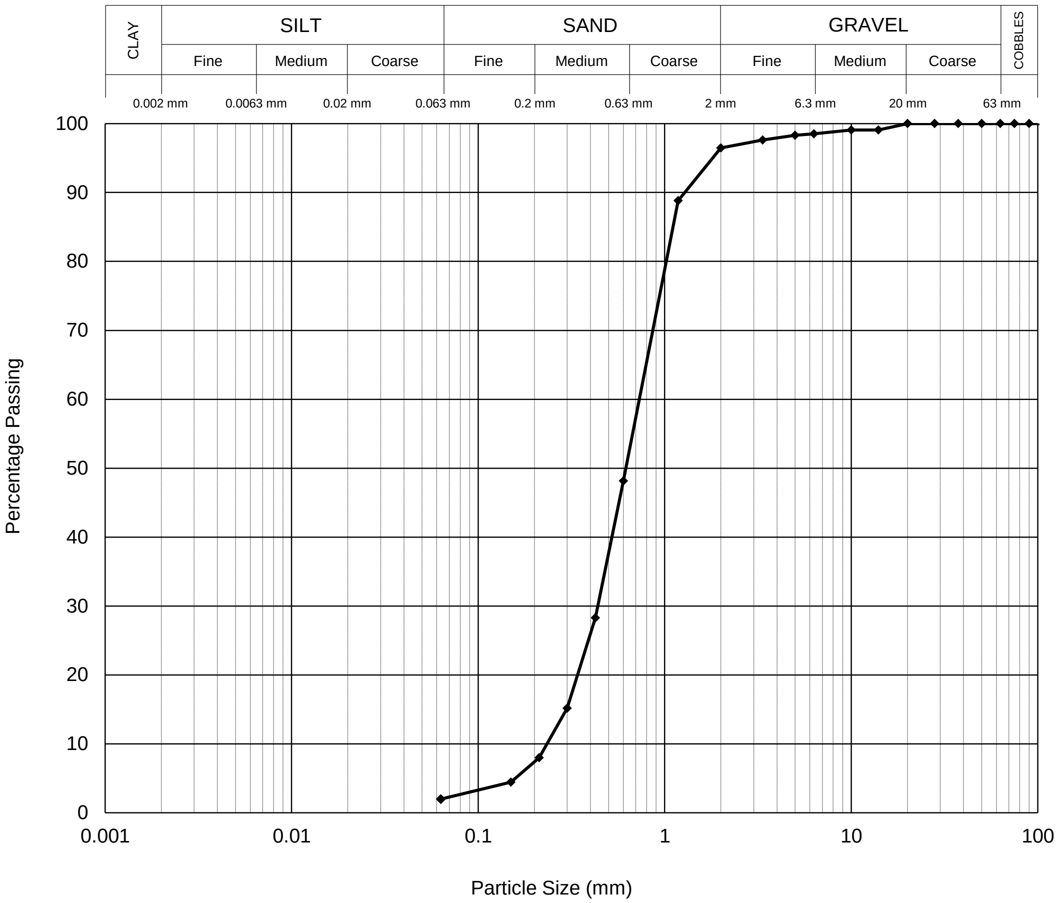
Location	BH16
Depth (m)	3.50-8.20
Sample Type	D

Description

Dark brown SAND with rare gravel and very fine shell fragments.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	99
10.0 mm	99
6.30 mm	99
5.00 mm	98
3.35 mm	98
2.00 mm	96
1.18 mm	89
600 µm	48
425 µm	28
300 µm	15
212 µm	8
150 µm	4
63 µm	2



Particle Proportions	
Cobbles	0.0
Gravel	3.5
Sand	94.5
Silt & Clay	2.0

Processed by CC
Checked and Approved by

J Sturges - Operations Manager
15/12/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

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1262 - PSD LAND 2 01.00 mixed sand sample from beach TP's D - 32168-383432.XLSM

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

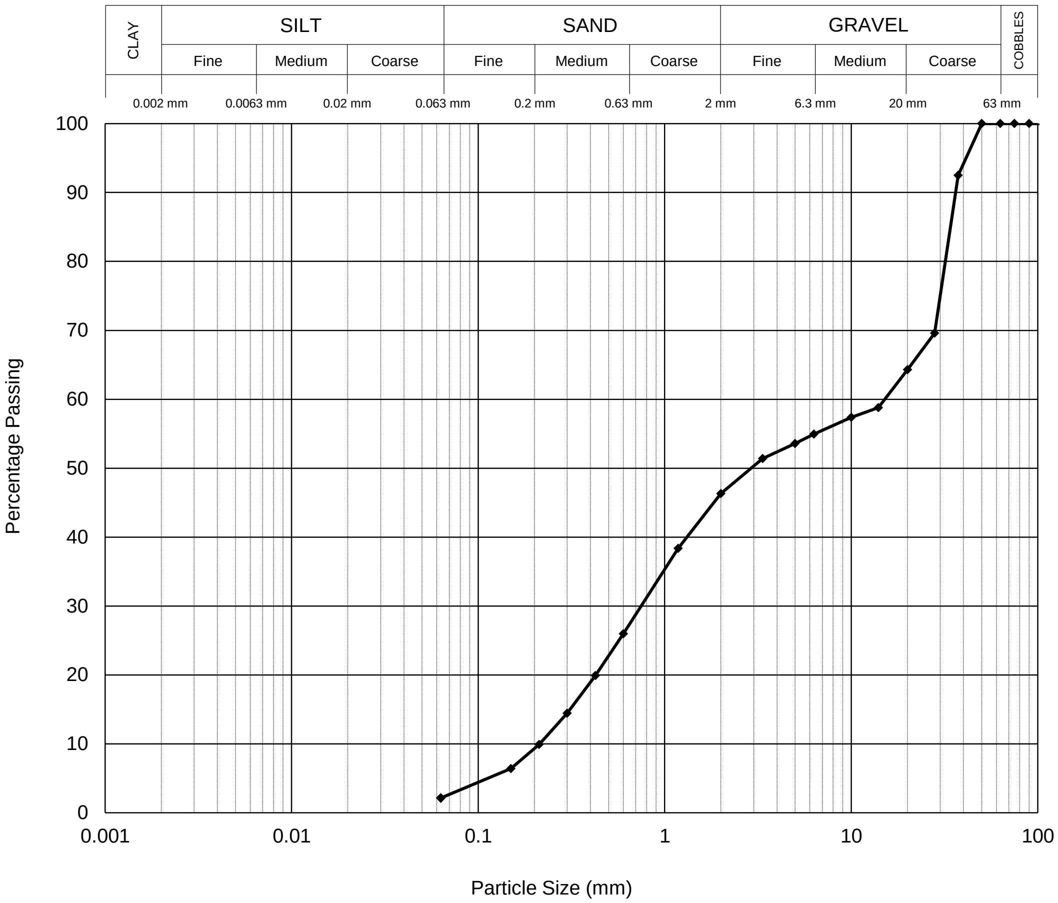
Location	LAND 2
Sample Ref	mixed sand sample from beach TP's
Depth (m)	1.00
Sample Type	D

Description

Dark brown and greyish brown SAND and GRAVEL.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	92
28.0 mm	70
20.0 mm	64
14.0 mm	59
10.0 mm	57
6.30 mm	55
5.00 mm	54
3.35 mm	51
2.00 mm	46
1.18 mm	38
600 µm	26
425 µm	20
300 µm	14
212 µm	10
150 µm	6
63 µm	2



Particle Proportions	
Cobbles	0.0
Gravel	53.7
Sand	44.2
Silt & Clay	2.1

Processed by CC
Checked and Approved by

J Sturges - Operations Manager
15/12/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

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UKAS TESTING 1982

Version 98.200730

Test Report By GEOLABS Limited Bucknalls Lane, Garston, Watford, Hertfordshire, WD25 9XX

Client : Geotron Caribbean B.V, Mauritslaan 1, Willemstad Curacao, ,

(Ref 1608026561)

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

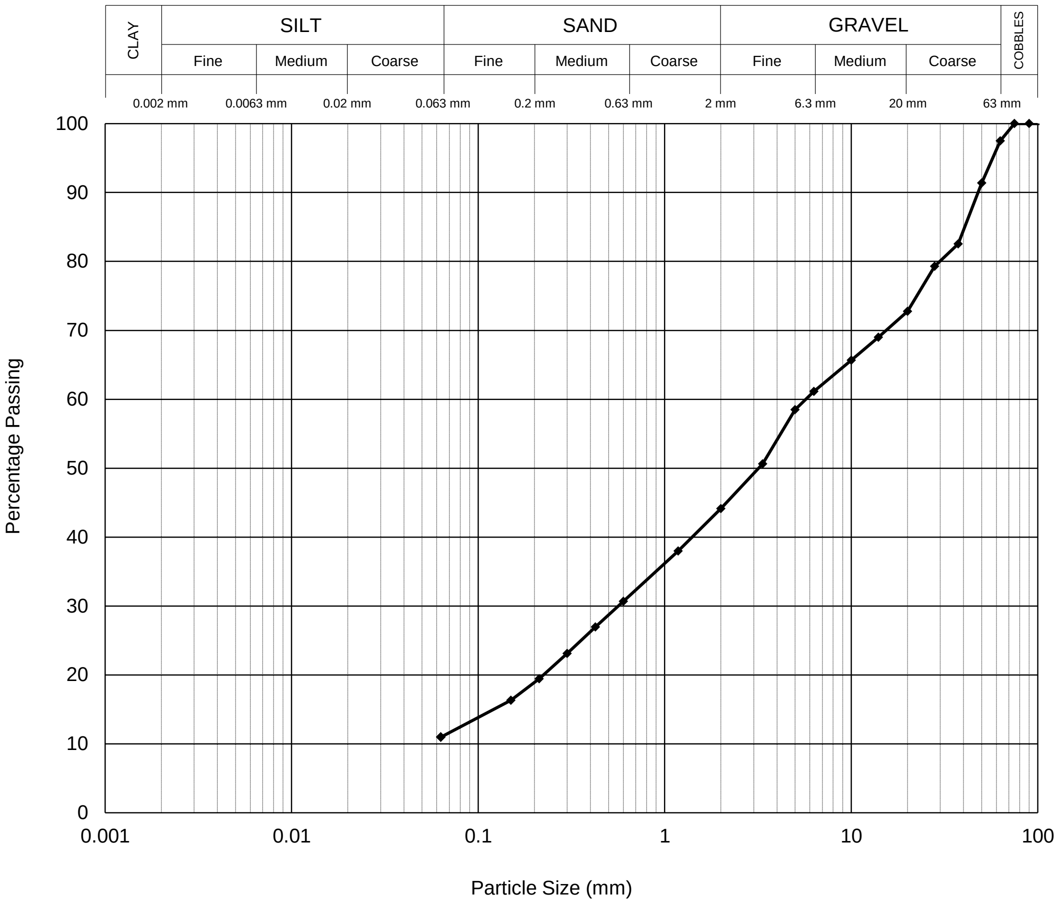
Location ROAD - DCP3
Sample Type B

Description

Pink silty sand and gravel sized ROCK with rare cobbles.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	98
50.0 mm	91
37.5 mm	83
28.0 mm	79
20.0 mm	73
14.0 mm	69
10.0 mm	66
6.30 mm	61
5.00 mm	58
3.35 mm	51
2.00 mm	44
1.18 mm	38
600 µm	31
425 µm	27
300 µm	23
212 µm	19
150 µm	16
63 µm	11



Particle Proportions	
Cobbles	2.5
Gravel	53.4
Sand	33.2
Silt & Clay	10.9

Processed by CC
Checked and Approved by

J Sturges - Operations Manager
15/12/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

Determination of Maximum and Minimum Dry Density of Sands

NGI-Geolabs Recommended Method Statement (As published in 'Development of new robust procedures for the determination of maximum and minimum dry densities of sand' by Knudsen.S et al at ISFOG 2020 {delayed publication})

Location	BH7
Sample Ref	combined
Depth (m)	3.00-8.00
Sample Type	amal

Description:

Dark brown fine SAND with rare shell fragments.

Percentage of material retained on the 2 mm test sieve 0.0 %

The fines content of the specimen has not been measured

Maximum Dry Density

Mean Maximum Dry Density 1.50 g/cm³

(after surcharge application)

Determination No 1

Maximum dry density **before** surcharge application	1.476	g/cm³
Maximum dry density **after** surcharge application	1.496	g/cm³
Shaker amplitude setting **before** surcharge application	2	
Shaker amplitude setting **after** surcharge application	2	

Determination No 2

Maximum dry density **before** surcharge application	1.476	g/cm³
Maximum dry density **after** surcharge application	1.496	g/cm³
Shaker amplitude setting **before** surcharge application	2	
Shaker amplitude setting **after** surcharge application	2	

Minimum Dry Density

Mean Minimum Dry Density 1.16 g/cm³

	Run		
Water calibrated volume of the mould		442.70	cm³
Mass of the mould		897.52	g
Mass of sand	1	512.58	g
	2	513.21	g
	3	512.90	g
	4	512.67	g
	5	513.30	g
	Mean	512.93	g

Checked and Approved by

C F Wallace - Technical Manager
16/12/2020

Project Number:
32168

Project Name:
BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

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SUMMARY OF CHEMICAL TESTS ON SOIL

Location	Depth m	Sample Ref	Sample Type	pH Value	Total Acid Soluble Sulphate as SO4 %	Water Soluble Sulphate as SO4 2:1 Water:Soil Extract g/l	Total Sulphur %	Water Soluble Chloride g/l	Water Soluble Nitrate g/l	Magnesium g/l	Organic Content %	Mass Loss on Ignition %	Carbonate Content %
BH1	0.30-2.00		D	-	-	-	-	-	-	-	-	-	< 0.10
BH3	6.20-7.00		D	-	-	-	-	-	-	-	-	-	< 0.10
BH7	3.00-3.45		D	-	-	-	-	-	-	-	< 0.40	-	-
BH7	7.00-8.00		D	-	-	-	-	-	-	-	-	-	< 0.10
BH9	1.00-1.50		D	-	-	-	-	-	-	-	-	-	27
BH9	6.30-7.50		D	-	-	-	-	-	-	-	0.57	-	-
BH10	6.00-8.00		D	-	-	-	-	-	-	-	-	-	7.5
BH11+15	1.00-2.00	1	D	-	-	-	-	-	-	-	< 0.40	-	-
BH12	3.00-3.50		D	-	-	-	-	-	-	-	-	-	10
BH16	3.50-8.20		D	-	-	-	-	-	-	-	11	-	24
BH8	4.00-6.00	AMAL		-	-	-	-	-	-	-	< 0.40	-	-

Tested by Chemtest Ltd : MCERTS / UKAS No 2183

Checked and Approved by:

J Sturges - Operations Manager
15/12/2020

Project Number:
GEO / 32168

Project Name:
BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

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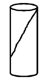
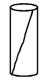
APPENDIX E LABORATORY RESULTS – ROCK

ISRM Suggested Methods – Rock Characterization Testing and Monitoring 1974 - 2006

UNIAXIAL COMPRESSIVE STRENGTH OF ROCK MATERIALS

Sample details					Density			Uniaxial Compression Test (LF0879C (1000kN) compression frame used)								
Borehole Ref.	Sample Ref.	Depth (m)	Description	MC (%)	Degree of Saturation (%)	Bulk (Mg/m³)	Dry (Mg/m³)	Mean after prep. Diameter (mm)	Mean after prep. Height (mm)	H/D Ratio	Load at Failure (kN)	UCS (MPa) 3 sig. fig.	Failure Sketch	D. Tested	Remarks
BH1		3.00-3.50	Pink ANDESITE	2.2	20.2	2.26	2.21	41.50	120.70	2.9	32.2	23.8		25/11/20	
BH2		1.30-1.50	Grey ANDESITE	0.7	10.9	2.48	2.47	41.60	120.60	2.9	89.2	65.6		25/11/20	
BH5		6.70-6.90	Red ANDESITE	5.0	26.6	1.97	1.88	41.50	113.60	2.7	12.1	8.95		25/11/20	
BH6B		0.50-0.70	Pimk/Grey ANDESITE	0.9	13.4	2.46	2.44	41.60	119.50	2.9	72.4	53.3		25/11/20	
BH10		4.30-4.45	Dark red ANDESITE	3.1	38.3	2.42	2.34	41.60	119.60	2.9	38.3	28.2		25/11/20	
BH11		1.45-1.60	LIMESTONE	15	55.4	1.86	1.61	40.60	95.50	2.4	12.3	9.5		25/11/20	
BH17		0.00-0.25	Coral LIMESTONE	3.3	32.8	2.32	2.25	41.60	120.80	2.9	32.0	23.5		25/11/20	
BH17		0.50-0.70	Coral LIMESTONE	3.8	35.9	2.31	2.23	41.50	125.50	3.0	32.3	23.9		25/11/20	
BH17		2.00-2.20	Coral LIMESTONE	24	60.9	1.67	1.35	40.60	96.50	2.4	2.1	1.62		25/11/20	

Note: The dimensional requirements of flatness (<0.02 mm), perpendicularity (<0.05 / 50 mm) and straightness (0.3 mm deviation) are all met. Specific Gravity used for Degree of Saturation is assumed unless specified by the client.

Checked and Approved by

CC

C Clergeaud (Snr. Geologist)

Date: 27/11/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

GEOLABS®

UKAS TESTING 1982

ISRM Suggested Methods – Rock Characterization Testing and Monitoring 1974 - 2006

UNIAXIAL COMPRESSIVE STRENGTH OF ROCK MATERIALS

Borehole Ref.:	BH1
Sample Ref.:	-
Depth (m):	3.00-3.50

Description:
Pink ANDESITE

Diameter	41.50 mm
Height	120.70 mm
Bulk Density	2.26 Mg/m³
Dry Density	2.21 Mg/m³
Water Content	2.2 %

Degree of Saturation: 20.2 % Specific Gravity: 2.9 Mg/m³ (Assumed)

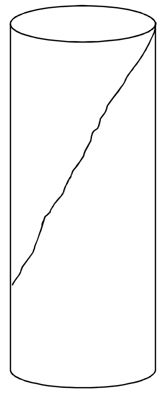
Test results

Unconfined Compressive Strength	23.8 MPa
Young's Modulus (tangential at 50% failure load)	n/a
Poisson's Ratio (tangential at 50% failure load)	n/a
Young's Modulus (secant at 10% failure load)	n/a
Poisson's Ratio (secant at 10% failure load)	n/a

LF0879C (1000kN) compression frame used

Failure Sketch

Mode of failure: Diagonal shearing



Solid lines for material failures.
Dashed lines for apparent weakness failure.

Date tested: 25/11/2020

Angle of foliation/Horizontal: n/a
Angle of shear plane/Horizontal: 115º

Sample type	**C**

Note: The dimensional requirements of Flatness (<0.02 mm), Perpendicularity (<0.05 / 50 mm) and Straightness (0.3 mm deviation) are all met.

Checked and Approved by
CC
C Clergeaud (Snr. Geologist)
Date: 27/11/2020

Project Number:
GEO / 32168

Project Name:
BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

GEOLABS
UKAS TESTING 1982

ISRM Suggested Methods – Rock Characterization Testing and Monitoring 1974 - 2006

UNIAXIAL COMPRESSIVE STRENGTH OF ROCK MATERIALS

Borehole Ref.:	BH2
Sample Ref.:	-
Depth (m):	1.30-1.50

Description:
Grey ANDESITE

Diameter	41.60 mm
Height	120.60 mm
Bulk Density	2.48 Mg/m³
Dry Density	2.47 Mg/m³
Water Content	0.7 %

Degree of Saturation: 10.9 %   Specific Gravity: 2.9 Mg/m³ (Assumed)

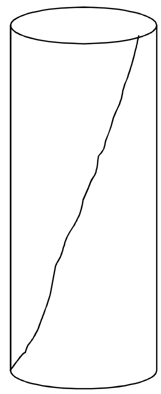
Test results

Unconfined Compressive Strength	65.6 MPa
Young's Modulus (tangential at 50% failure load)	n/a
Poisson's Ratio (tangential at 50% failure load)	n/a
Young's Modulus (secant at 10% failure load)	n/a
Poisson's Ratio (secant at 10% failure load)	n/a

LF0879C (1000kN) compression frame used

Failure Sketch

Mode of failure: Diagonal shearing



Solid lines for material failures.
Dashed lines for apparent weakness failure.

Date tested: 25/11/2020

Angle of foliation/Horizontal: n/a
Angle of shear plane/Horizontal: 105º

Sample type	**C**

Note: The dimensional requirements of Flatness (<0.02 mm), Perpendicularity (<0.05 / 50 mm) and Straightness (0.3 mm deviation) are all met.

Checked and Approved by

CC

C Clergeaud (Snr. Geologist)

Date: 27/11/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

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ISRM Suggested Methods – Rock Characterization Testing and Monitoring 1974 - 2006

UNIAXIAL COMPRESSIVE STRENGTH OF ROCK MATERIALS

Borehole Ref.:	BH5
Sample Ref.:	-
Depth (m):	6.70-6.90

Description:
Red ANDESITE

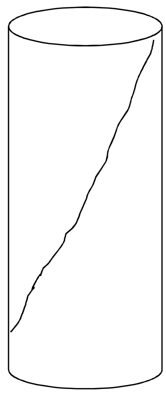
Diameter	41.50 mm
Height	113.60 mm
Bulk Density	1.97 Mg/m³
Dry Density	1.88 Mg/m³
Water Content	5.0 %

Degree of Saturation: 26.6 %   Specific Gravity: 2.9 Mg/m³ (Assumed)

LF0879C (1000kN) compression frame used

Failure Sketch

Mode of failure: Diagonal shearing



Solid lines for material failures.
Dashed lines for apparent weakness failure.

Date tested: 25/11/2020

Angle of foliation/Horizontal: n/a
Angle of shear plane/Horizontal: 105º

Sample type	**C**

Test results

Unconfined Compressive Strength	8.95 MPa
Young's Modulus (tangential at 50% failure load)	n/a
Poisson's Ratio (tangential at 50% failure load)	n/a
Young's Modulus (secant at 10% failure load)	n/a
Poisson's Ratio (secant at 10% failure load)	n/a

Note: The dimensional requirements of Flatness (<0.02 mm), Perpendicularity (<0.05 / 50 mm) and Straightness (0.3 mm deviation) are all met.

Checked and Approved by

CC

C Clergeaud (Snr. Geologist)

Date: 27/11/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

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UKAS TESTING 1982

ISRM Suggested Methods – Rock Characterization Testing and Monitoring 1974 - 2006

UNIAXIAL COMPRESSIVE STRENGTH OF ROCK MATERIALS

Borehole Ref.:	BH6B
Sample Ref.:	-
Depth (m):	0.50-0.70

Description:
Pimk/Grey ANDESITE

Diameter	41.60 mm
Height	119.50 mm
Bulk Density	2.46 Mg/m³
Dry Density	2.44 Mg/m³
Water Content	0.9 %

Degree of Saturation: 13.4 %   Specific Gravity: 2.9 Mg/m³ (Assumed)

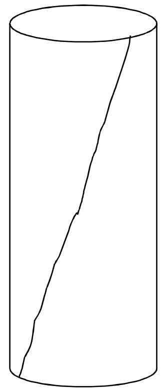
Test results

Unconfined Compressive Strength	53.3 MPa
Young's Modulus (tangential at 50% failure load)	n/a
Poisson's Ratio (tangential at 50% failure load)	n/a
Young's Modulus (secant at 10% failure load)	n/a
Poisson's Ratio (secant at 10% failure load)	n/a

LF0879C (1000kN) compression frame used

Failure Sketch

Mode of failure: Diagonal shearing



Solid lines for material failures.
Dashed lines for apparent weakness failure.

Date tested: 25/11/2020

Angle of foliation/Horizontal: n/a
Angle of shear plane/Horizontal: 115º

Sample type	C

Note: The dimensional requirements of Flatness (<0.02 mm), Perpendicularity (<0.05 / 50 mm) and Straightness (0.3 mm deviation) are all met.

Checked and Approved by
CC
C Clergeaud (Snr. Geologist)
Date: 27/11/2020

Project Number:
GEO / 32168
Project Name:
BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

GEOLABS®
UKAS TESTING 1982

ISRM Suggested Methods – Rock Characterization Testing and Monitoring 1974 - 2006

UNIAXIAL COMPRESSIVE STRENGTH OF ROCK MATERIALS

Borehole Ref.:	BH10
Sample Ref.:	-
Depth (m):	4.30-4.45

Description:
Dark red ANDESITE

Diameter	41.60 mm
Height	119.60 mm
Bulk Density	2.42 Mg/m³
Dry Density	2.34 Mg/m³
Water Content	3.1 %

Degree of Saturation: 38.3 %   Specific Gravity: 2.9 Mg/m³ (Assumed)

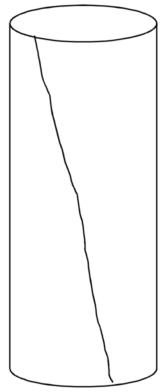
Test results

Unconfined Compressive Strength	28.2 MPa
Young's Modulus (tangential at 50% failure load)	n/a
Poisson's Ratio (tangential at 50% failure load)	n/a
Young's Modulus (secant at 10% failure load)	n/a
Poisson's Ratio (secant at 10% failure load)	n/a

LF0879C (1000kN) compression frame used

Failure Sketch

Mode of failure: Diagonal shearing



Solid lines for material failures.
Dashed lines for apparent weakness failure.

Date tested: 25/11/2020

Angle of foliation/Horizontal: n/a
Angle of shear plane/Horizontal: 75º

Sample type	**C**

Note: The dimensional requirements of Flatness (<0.02 mm), Perpendicularity (<0.05 / 50 mm) and Straightness (0.3 mm deviation) are all met.

Checked and Approved by
CC
C Clergeaud (Snr. Geologist)
Date: 27/11/2020

Project Number:
GEO / 32168

Project Name:
BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

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UKAS TESTING 1982

ISRM Suggested Methods – Rock Characterization Testing and Monitoring 1974 - 2006

UNIAXIAL COMPRESSIVE STRENGTH OF ROCK MATERIALS

Borehole Ref.:	BH11
Sample Ref.:	-
Depth (m):	1.45-1.60

Description:
LIMESTONE

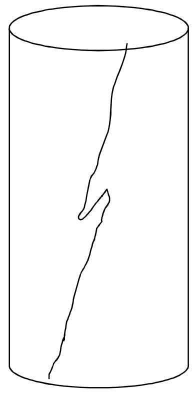
Diameter	40.60 mm
Height	95.50 mm
Bulk Density	1.86 Mg/m³
Dry Density	1.61 Mg/m³
Water Content	15 %

Degree of Saturation: 55.4 %   Specific Gravity: 2.9 Mg/m³ (Assumed)

LF0879C (1000kN) compression frame used

Failure Sketch

Mode of failure: Diagonal shearing



Solid lines for material failures.
Dashed lines for apparent weakness failure.

Date tested: 25/11/2020

Angle of foliation/Horizontal: n/a
Angle of shear plane/Horizontal: 100º

Sample type	**C**

Test results

Unconfined Compressive Strength	9.5 MPa
Young's Modulus (tangential at 50% failure load)	n/a
Poisson's Ratio (tangential at 50% failure load)	n/a
Young's Modulus (secant at 10% failure load)	n/a
Poisson's Ratio (secant at 10% failure load)	n/a

Note: The dimensional requirements of Flatness (<0.02 mm), Perpendicularity (<0.05 / 50 mm) and Straightness (0.3 mm deviation) are all met.

Checked and Approved by
CC
C Clergeaud (Snr. Geologist)
Date: 27/11/2020

Project Number:
GEO / 32168

Project Name:
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GIO20001

ISRM Suggested Methods – Rock Characterization Testing and Monitoring 1974 - 2006

UNIAXIAL COMPRESSIVE STRENGTH OF ROCK MATERIALS

Borehole Ref.:	BH17
Sample Ref.:	-
Depth (m):	0.00-0.25

Description:
Coral LIMESTONE

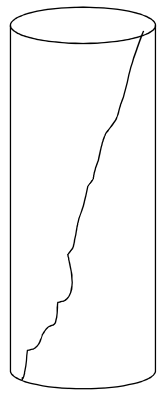
Diameter	41.60 mm
Height	120.80 mm
Bulk Density	2.32 Mg/m³
Dry Density	2.25 Mg/m³
Water Content	3.3 %

Degree of Saturation: 32.8 % Specific Gravity: 2.9 Mg/m³ (Assumed)

LF0879C (1000kN) compression frame used

Failure Sketch

Mode of failure: Diagonal shearing



Solid lines for material failures.
Dashed lines for apparent weakness failure.

Date tested: 25/11/2020

Angle of foliation/Horizontal: n/a
Angle of shear plane/Horizontal: 105º

Sample type	**C**

Test results

Unconfined Compressive Strength	23.5 MPa
Young's Modulus (tangential at 50% failure load)	n/a
Poisson's Ratio (tangential at 50% failure load)	n/a
Young's Modulus (secant at 10% failure load)	n/a
Poisson's Ratio (secant at 10% failure load)	n/a

Note: The dimensional requirements of Flatness (<0.02 mm), Perpendicularity (<0.05 / 50 mm) and Straightness (0.3 mm deviation) are all met.

Checked and Approved by

CC

C Clergeaud (Snr. Geologist)

Date: 27/11/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
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UNIAXIAL COMPRESSIVE STRENGTH OF ROCK MATERIALS

Borehole Ref.:	BH17
Sample Ref.:	-
Depth (m):	0.50-0.70

Description:
Coral LIMESTONE

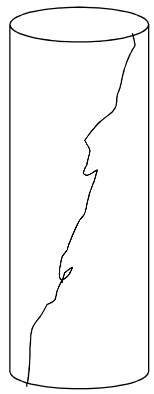
Diameter	41.50 mm
Height	125.50 mm
Bulk Density	2.31 Mg/m³
Dry Density	2.23 Mg/m³
Water Content	3.8 %

Degree of Saturation: 35.9 % Specific Gravity: 2.9 Mg/m³ (Assumed)

LF0879C (1000kN) compression frame used

Failure Sketch

Mode of failure: Diagonal shearing



Solid lines for material failures.
Dashed lines for apparent weakness failure.

Date tested: 25/11/2020

Angle of foliation/Horizontal: n/a
Angle of shear plane/Horizontal: 75º

Sample type	**C**

Test results

Unconfined Compressive Strength	23.9 MPa
Young's Modulus (tangential at 50% failure load)	n/a
Poisson's Ratio (tangential at 50% failure load)	n/a
Young's Modulus (secant at 10% failure load)	n/a
Poisson's Ratio (secant at 10% failure load)	n/a

Note: The dimensional requirements of Flatness (<0.02 mm), Perpendicularity (<0.05 / 50 mm) and Straightness (0.3 mm deviation) are all met.

Checked and Approved by

CC

C Clergeaud (Snr. Geologist)

Date: 27/11/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
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UNIAXIAL COMPRESSIVE STRENGTH OF ROCK MATERIALS

Borehole Ref.:	BH17
Sample Ref.:	-
Depth (m):	2.00-2.20

Description:
Coral LIMESTONE

Diameter	40.60 mm
Height	96.50 mm
Bulk Density	1.67 Mg/m³
Dry Density	1.35 Mg/m³
Water Content	24 %

Degree of Saturation: 60.9 % Specific Gravity: 2.9 Mg/m³ (Assumed)

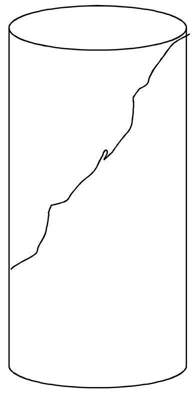
Test results

Unconfined Compressive Strength	1.62 MPa
Young's Modulus (tangential at 50% failure load)	n/a
Poisson's Ratio (tangential at 50% failure load)	n/a
Young's Modulus (secant at 10% failure load)	n/a
Poisson's Ratio (secant at 10% failure load)	n/a

LF0879C (1000kN) compression frame used

Failure Sketch

Mode of failure: Diagonal shearing



Solid lines for material failures.
Dashed lines for apparent weakness failure.

Date tested: 25/11/2020

Angle of foliation/Horizontal: n/a
Angle of shear plane/Horizontal: 105º

Sample type	C

Note: The dimensional requirements of Flatness (<0.02 mm), Perpendicularity (<0.05 / 50 mm) and Straightness (0.3 mm deviation) are all met.

Checked and Approved by
CC
C Clergeaud (Snr. Geologist)
Date: 27/11/2020

Project Number:
GEO / 32168

Project Name:
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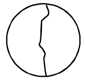
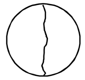
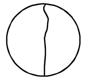
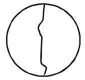
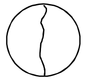
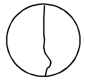
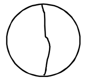
ISRM Suggested Methods – Rock Characterization Testing and Monitoring 1974 - 2006

INDIRECT TENSILE STRENGTH BY THE BRAZIL TEST

Sample details				Indirect Tensile Strength test (LF0879C (1000kN) compression frame used)												
Borehole Ref.	Sample Ref.	Depth (m)	Description	D. Tested	Sample Diameter (mm)	Sample Width (mm)	Degree of Saturation (%)	Water Content (%)	Specific Gravity* (Mg/m³)	Stress Rate (N/s)	Test Duration (min:sec)	Failure Sketch	Failure Load (kN)	Tensile Strength (MPa)	Remarks
BH1		3.00-3.50	Pink ANDESITE	25/11/20	41.60	22.10	14.4	1.6	2.90 (a)	200	00:21		4.20	2.91	
BH2		1.30-1.50	Grey ANDESITE	25/11/20	41.60	21.60	22.4	1.5	2.90 (a)	200	00:56		11.30	8	
BH6B		0.50-0.70	Pimk/Grey ANDESITE	25/11/20	41.60	20.60	13.5	0.9	2.90 (a)	200	00:36		7.30	5.42	
BH11		1.45-1.60	LIMESTONE	25/11/20	40.80	22.20	34.5	6.0	2.90 (a)	200	00:32		6.30	4.42	
BH17		0.00-0.25	Coral LIMESTONE	25/11/20	41.40	22.50	23.4	2.5	2.90 (a)	200	00:38		7.50	5.12	
BH17		0.50-0.70	Coral LIMESTONE	25/11/20	41.50	22.50	19.3	1.9	2.90 (a)	200	00:40		8.10	5.52	
BH17		2.00-2.20	Coral LIMESTONE	25/11/20	40.60	19.70	100	31.1	2.90 (a)	200	00:02		0.30	0.239	

* Specific Gravity: (a) assumed or (m) measured/supplied by client.

Checked and Approved by

CC

C Clergeaud (Snr. Geologist)

Date: 27/11/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS
GIO20001

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UKAS TESTING 1982

ISRM Suggested Methods – Rock Characterization Testing and Monitoring 1974 - 2006

INDIRECT TENSILE STRENGTH BY THE BRAZIL TEST

Borehole Ref.:	BH1
Sample Ref.:	
Depth (m):	3.00-3.50

Description:
Pink ANDESITE

Sample Details

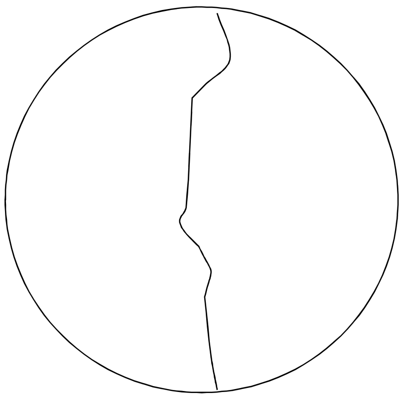
Diameter	41.60 mm
Thickness	22.10 mm
Thickness / Diameter Ratio	0.53
Bulk Density	2.24 Mg/m³
Dry Density	2.21 Mg/m³
Water Content	1.6 %
Specific Gravity (Assumed)	2.90 Mg/m³
Degree of Saturation	14.4 %

Test Results

Stress Rate	0.20 kN/s
Test Duration	00:21 min:sec
Angle of loading with respect to anisotropy	90 °

Failure Sketch

Mode of failure: Axial Split



Solid lines for material failures. Dashed lines for apparent weakness failure.

LF0879C (1000kN) compression frame and steel loading jaws used

Date tested: 25/11/2020

Failure Load
4.20 kN

Tensile Strength
2.91 MPa

Sample type: C

Remarks:

Note: The dimensional requirements of Flatness (<0.25 mm), Perpendicularity (to within 0.25º) and irregularities across thickness (< 0.025 mm) are all met.

Checked and Approved by

CC

C Clergeaud (Snr. Geologist)

Date: 27/11/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS GIO20001

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INDIRECT TENSILE STRENGTH BY THE BRAZIL TEST

Borehole Ref.:	BH2
Sample Ref.:	
Depth (m):	1.30-1.50

Description:
Grey ANDESITE

Sample Details

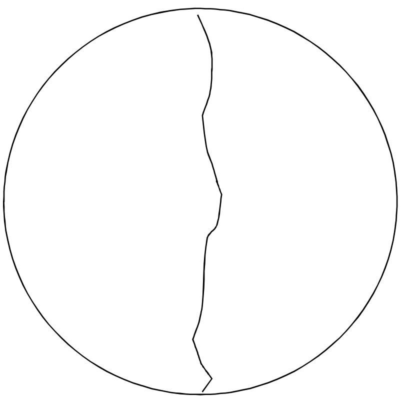
Diameter	41.60 mm
Thickness	21.60 mm
Thickness / Diameter Ratio	0.52
Bulk Density	2.46 Mg/m³
Dry Density	2.42 Mg/m³
Water Content	1.5 %
Specific Gravity (Assumed)	2.90 Mg/m³
Degree of Saturation	22.4 %

Test Results

Stress Rate	0.20 kN/s
Test Duration	00:56 min:sec
Angle of loading with respect to anisotropy	90 °

Failure Sketch

Mode of failure: Axial Split



Solid lines for material failures. Dashed lines for apparent weakness failure.

LF0879C (1000kN) compression frame and steel loading jaws used

Date tested: 25/11/2020

Failure Load
11.30 kN

Tensile Strength
8 MPa

Sample type: C

Remarks:

Note: The dimensional requirements of Flatness (<0.25 mm), Perpendicularity (to within 0.25º) and irregularities across thickness (< 0.025 mm) are all met.

Checked and Approved by

CC

C Clergeaud (Snr. Geologist)

Date: 27/11/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS GIO20001

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INDIRECT TENSILE STRENGTH BY THE BRAZIL TEST

Borehole Ref.:	BH6B
Sample Ref.:	
Depth (m):	0.50-0.70

Description:
Pimk/Grey ANDESITE

Sample Details

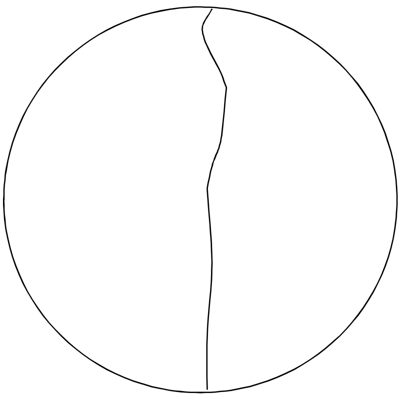
Diameter	41.60 mm
Thickness	20.60 mm
Thickness / Diameter Ratio	0.50
Bulk Density	2.46 Mg/m³
Dry Density	2.44 Mg/m³
Water Content	0.9 %
Specific Gravity (Assumed)	2.90 Mg/m³
Degree of Saturation	13.5 %

Test Results

Stress Rate	0.20 kN/s
Test Duration	00:36 min:sec
Angle of loading with respect to anisotropy	90 º

Failure Sketch

Mode of failure: Axial Split



Solid lines for material failures. Dashed lines for apparent weakness failure.

LF0879C (1000kN) compression frame and steel loading jaws used

Date tested: 25/11/2020

Failure Load	**7.30 kN**
Tensile Strength	**5.42 MPa**

Sample type: C

Remarks:

Note: The dimensional requirements of Flatness (<0.25 mm), Perpendicularity (to within 0.25º) and irregularities across thickness (< 0.025 mm) are all met.

Checked and Approved by

CC

C Clergeaud (Snr. Geologist)

Date: 27/11/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS GIO20001

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INDIRECT TENSILE STRENGTH BY THE BRAZIL TEST

Borehole Ref.:	BH11
Sample Ref.:	
Depth (m):	1.45-1.60

Description:
LIMESTONE

Sample Details

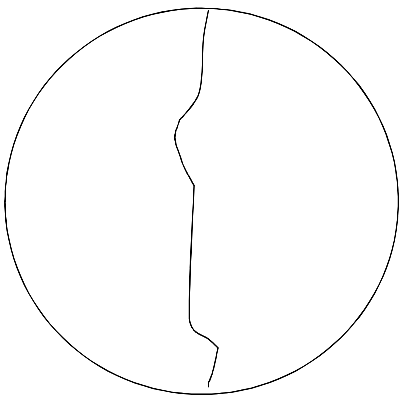
Diameter	40.80 mm
Thickness	22.20 mm
Thickness / Diameter Ratio	0.54
Bulk Density	2.04 Mg/m³
Dry Density	1.93 Mg/m³
Water Content	6.0 %
Specific Gravity (Assumed)	2.90 Mg/m³
Degree of Saturation	34.5 %

Test Results

Stress Rate	0.20 kN/s
Test Duration	00:32 min:sec
Angle of loading with respect to anisotropy	90 º

Failure Sketch

Mode of failure: Axial Split



Solid lines for material failures. Dashed lines for apparent weakness failure.

LF0879C (1000kN) compression frame and steel loading jaws used

Date tested: 25/11/2020

Failure Load
6.30 kN

Tensile Strength
4.42 MPa

Sample type: C

Remarks:

Note: The dimensional requirements of Flatness (<0.25 mm), Perpendicularity (to within 0.25º) and irregularities across thickness (< 0.025 mm) are all met.

Checked and Approved by

CC

C Clergeaud (Snr. Geologist)

Date: 27/11/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS GIO20001

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INDIRECT TENSILE STRENGTH BY THE BRAZIL TEST

Borehole Ref.:	BH17
Sample Ref.:	
Depth (m):	0.00-0.25

Description:
Coral LIMESTONE

Sample Details

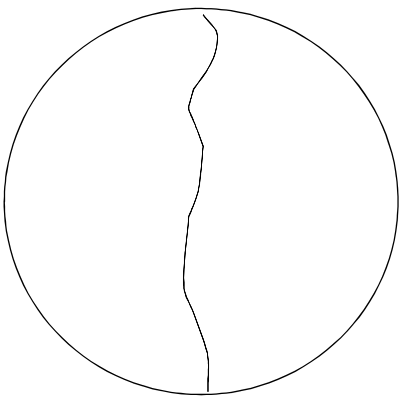
Diameter	41.40 mm
Thickness	22.50 mm
Thickness / Diameter Ratio	0.54
Bulk Density	2.26 Mg/m³
Dry Density	2.21 Mg/m³
Water Content	2.5 %
Specific Gravity (Assumed)	2.90 Mg/m³
Degree of Saturation	23.4 %

Test Results

Stress Rate	0.20 kN/s
Test Duration	00:38 min:sec
Angle of loading with respect to anisotropy	90 °

Failure Sketch

Mode of failure: Axial Split



Solid lines for material failures. Dashed lines for apparent weakness failure.

LF0879C (1000kN) compression frame and steel loading jaws used

Date tested: 25/11/2020

Failure Load
7.50 kN

Tensile Strength
5.12 MPa

Sample type: C

Remarks:

Note: The dimensional requirements of Flatness (<0.25 mm), Perpendicularity (to within 0.25°) and irregularities across thickness (< 0.025 mm) are all met.

Checked and Approved by

CC

C Clergeaud (Snr. Geologist)

Date: 27/11/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS GIO20001

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INDIRECT TENSILE STRENGTH BY THE BRAZIL TEST

Borehole Ref.:	BH17
Sample Ref.:	
Depth (m):	0.50-0.70

Description:
Coral LIMESTONE

Sample Details

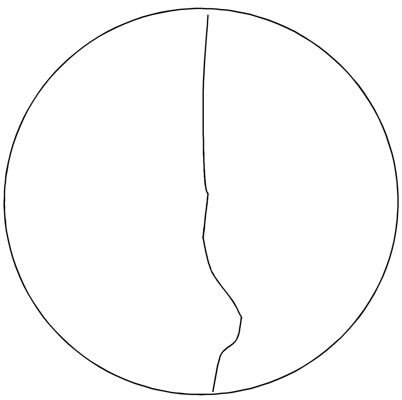
Diameter	41.50 mm
Thickness	22.50 mm
Thickness / Diameter Ratio	0.54
Bulk Density	2.29 Mg/m^3
Dry Density	2.25 Mg/m^3
Water Content	1.9 %
Specific Gravity (Assumed)	2.90 Mg/m^3
Degree of Saturation	19.3 %

Test Results

Stress Rate	0.20 kN/s
Test Duration	00:40 min:sec
Angle of loading with respect to anisotropy	90 °

Failure Sketch

Mode of failure: Axial Split



Solid lines for material failures. Dashed lines for apparent weakness failure.

LF0879C (1000kN) compression frame and steel loading jaws used

Date tested: 25/11/2020

Failure Load	**8.10 kN**
Tensile Strength	**5.52 MPa**

Sample type: C

Remarks:

Note: The dimensional requirements of Flatness (<0.25 mm), Perpendicularity (to within 0.25°) and irregularities across thickness (< 0.025 mm) are all met.

Checked and Approved by

CC

C Clergeaud (Snr. Geologist)

Date: 27/11/2020

Project Number: **GEO / 32168**

Project Name: **BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS GIO20001**

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INDIRECT TENSILE STRENGTH BY THE BRAZIL TEST

Borehole Ref.:	BH17
Sample Ref.:	
Depth (m):	2.00-2.20

Description:
Coral LIMESTONE

Sample Details

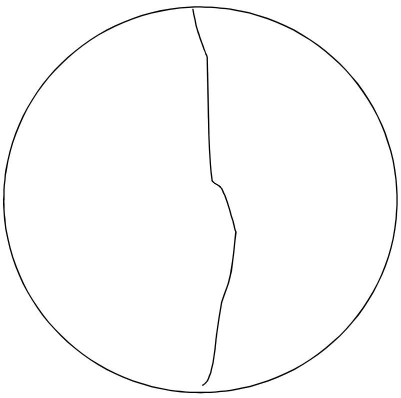
Diameter	40.60 mm
Thickness	19.70 mm
Thickness / Diameter Ratio	0.49
Bulk Density	2.55 Mg/m³
Dry Density	1.94 Mg/m³
Water Content	31.1 %
Specific Gravity (Assumed)	2.90 Mg/m³
Degree of Saturation	100.0 %

Test Results

Stress Rate	0.20 kN/s
Test Duration	00:02 min:sec
Angle of loading with respect to anisotropy	90 °

Failure Sketch

Mode of failure: Axial Split



Solid lines for material failures. Dashed lines for apparent weakness failure.

LF0879C (1000kN) compression frame and steel loading jaws used

Date tested: 25/11/2020

Failure Load
0.30 kN

Tensile Strength
0.239 MPa

Sample type: C

Remarks:

Note: The dimensional requirements of Flatness (<0.25 mm), Perpendicularity (to within 0.25°) and irregularities across thickness (< 0.025 mm) are all met.

Checked and Approved by

CC

C Clergeaud (Snr. Geologist)

Date: 27/11/2020

Project Number:

GEO / 32168

Project Name:

BLACK ROCK HARBOUR SABA CARIBBEAN NETHERLANDS GIO20001

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APPENDIX F LABORATORY RESULTS – CHEMICAL TESTS

Aquifer Advies
T.a.v. Ben den Toom
Dr. Langeveldplein 6
3361 HE SLIEDRECHT

Analysecertificaat

Datum: 19-Nov-2020

Hierbij ontvangt u de resultaten van het navolgende laboratoriumonderzoek.

Certificaatnummer/Versie	2020181273/1
Uw project/verslagnummer	20106
Uw projectnaam	Saba
Uw ordernummer	20106
Monster(s) ontvangen	12-Nov-2020

Dit certificaat mag uitsluitend in zijn geheel worden gereproduceerd.
De analyse resultaten hebben alleen betrekking op het beproefde object.

De grondmonsters worden tot 4 weken na datum ontvangst bewaard en watermonsters tot 2 weken na datum ontvangst. Zonder tegenbericht worden de monsters nadien afgevoerd.
Indien de monsters langer bewaard dienen te blijven verzoeken wij U dit exemplaar uiterlijk 1 werkdag voor afloop van de standaardbewaarperiode ondertekend aan ons te retourneren. Voor de kosten van het langer bewaren van monsters verwijzen wij naar de prijslijst.

Bewaren tot:
Datum: Naam: Handtekening:

Wij vertrouwen erop uw opdracht hiermee naar verwachting te hebben uitgevoerd, mocht U naar aanleiding van dit analysecertificaat nog vragen hebben verzoeken wij U contact op te nemen met de afdeling Verkoop en Advies.

Met vriendelijke groet,

Eurofins Analytico B.V.

Ing. A. Veldhuizen
Technical Manager

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Analysecertificaat

Uw project/verslagnummer	20106	Certificaatnummer/Versie	2020181273/1
Uw projectnaam	Saba	Startdatum analyse	13-Nov-2020
Uw ordernummer	20106	Datum einde analyse	19-Nov-2020
Uw monsternemer	Adrie Lamore	Rapportagedatum	19-Nov-2020/16:43
		Bijlage	A,B,C
		Pagina	1/3
Projectcode	5185 - Aquifer - Project Waterbodem		

	Analyse	Eenheid	1	2
	Bodemkundige analyses			
S	Droge stof	% (m/m)	81.9	75.5
S	Organische stof	% (m/m) ds	1.7	1.2
Q	Gloeirest	% (m/m) ds	98	99
S	Korrelgrootte < 2 µm, gravimetrisch	% (m/m) ds	<2.0	<2.0
	Metalen			
S	Arseen (As)	mg/kg ds	<4.0	<4.0
S	Cadmium (Cd)	mg/kg ds	<0.20	<0.20
S	Chroom (Cr)	mg/kg ds	16	15
S	Koper (Cu)	mg/kg ds	12	11
S	Kwik (Hg)	mg/kg ds	<0.050	<0.050
S	Nikkel (Ni)	mg/kg ds	13	8.5
S	Lood (Pb)	mg/kg ds	<10	<10
S	Zink (Zn)	mg/kg ds	21	22
	Minerale olie			
	Minerale olie (C10-C12)	mg/kg ds	<3.0	<3.0
	Minerale olie (C12-C16)	mg/kg ds	<5.0	<5.0
	Minerale olie (C16-C21)	mg/kg ds	<5.0	<5.0
	Minerale olie (C21-C30)	mg/kg ds	<11	<11
	Minerale olie (C30-C35)	mg/kg ds	<5.0	<5.0
	Minerale olie (C35-C40)	mg/kg ds	<6.0	<6.0
S	Minerale olie totaal (C10-C40)	mg/kg ds	<35	<35
	Organo chloorbestrijdingsmiddelen, OCB			
S	alfa-HCH	mg/kg ds	<0.0010	<0.0010
S	beta-HCH	mg/kg ds	<0.0010	<0.0010
S	gamma-HCH	mg/kg ds	<0.0010	<0.0010
S	delta-HCH	mg/kg ds	<0.0010	<0.0010
S	Hexachloorbenzeen	mg/kg ds	<0.0010	<0.0010
S	Heptachloor	mg/kg ds	<0.0010	<0.0010
S	Heptachloorepoxide(cis- of A)	mg/kg ds	<0.0010	<0.0010

Nr.	Uw monsteromschrijving	Opgegeven monstermatrix	Monster nr.
1	Waterbodem 1	Waterbodem (AS3000)	11700486
2	mix B11 + B15	Waterbodem (AS3000)	11700487

Q: door RvA geaccrediteerde verrichting
A: AP04 erkende en geaccrediteerde verrichting
S: AS SIKB erkende en geaccrediteerde verrichting
V: VLAREL erkende verrichting
W: Waals Gewest erkende verrichting

Dit certificaat mag uitsluitend in zijn geheel worden gereproduceerd.

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KvK/CoC No. 09088623
BTW/VAT No. NL 8043.14.883.B01

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Analysecertificaat

Uw project/verslagnummer	20106	Certificaatnummer/Versie	2020181273/1
Uw projectnaam	Saba	Startdatum analyse	13-Nov-2020
Uw ordernummer	20106	Datum einde analyse	19-Nov-2020
Uw monsternemer	Adrie Lamore	Rapportagedatum	19-Nov-2020/16:43
		Bijlage	A,B,C
		Pagina	2/3
Projectcode	5185 - Aquifer - Project Waterbodem		

	Analyse	Eenheid	1	2
S	Heptachloorepoxide(trans- of B)	mg/kg ds	<0.0010	<0.0010
S	Hexachloorbutadieen	mg/kg ds	<0.0010	<0.0010
S	Aldrin	mg/kg ds	<0.0010	<0.0010
S	Dieldrin	mg/kg ds	<0.0010	<0.0010
S	Endrin	mg/kg ds	<0.0010	<0.0010
S	Isodrin	mg/kg ds	<0.0010	<0.0010
S	Telodrin	mg/kg ds	<0.0010	<0.0010
S	alfa-Endosulfan	mg/kg ds	<0.0010	<0.0010
Q	beta-Endosulfan	mg/kg ds	<0.0010	<0.0010
S	Endosulfansulfaat	mg/kg ds	<0.0020	<0.0020
S	alfa-Chloordaan	mg/kg ds	<0.0010	<0.0010
S	gamma-Chloordaan	mg/kg ds	<0.0010	<0.0010
S	o,p'-DDT	mg/kg ds	<0.0010	<0.0010
S	p,p'-DDT	mg/kg ds	<0.0010	<0.0010
S	o,p'-DDE	mg/kg ds	<0.0010	<0.0010
S	p,p'-DDE	mg/kg ds	<0.0010	<0.0010
S	o,p'-DDD	mg/kg ds	<0.0010	<0.0010
S	p,p'-DDD	mg/kg ds	<0.0010	<0.0010
S	HCH (som) (factor 0,7)	mg/kg ds	0.0028 1)	0.0028 1)
S	Drins (som) (factor 0,7)	mg/kg ds	0.0021 1)	0.0021 1)
S	Heptachloorepoxide (som) (factor 0,7)	mg/kg ds	0.0014 1)	0.0014 1)
S	DDD (som) (factor 0,7)	mg/kg ds	0.0014 1)	0.0014 1)
S	DDE (som) (factor 0,7)	mg/kg ds	0.0014 1)	0.0014 1)
S	DDT (som) (factor 0,7)	mg/kg ds	0.0014 1)	0.0014 1)
S	DDX (som) (factor 0,7)	mg/kg ds	0.0042 1)	0.0042 1)
S	Chloordaan (som) (factor 0,7)	mg/kg ds	0.0014 1)	0.0014 1)
S	OCB (som) LB (factor 0,7)	mg/kg ds	0.015 1)	0.015 1)
S	OCB (som) WB (factor 0,7)	mg/kg ds	0.017 1)	0.017 1)
	Polychloorbifenylen, PCB			
S	PCB 28	mg/kg ds	<0.0010	<0.0010
S	PCB 52	mg/kg ds	<0.0010	<0.0010

Nr.	Uw monsteromschrijving	Opgegeven monstermatrix	Monster nr.
1	Waterbodem 1	Waterbodem (AS3000)	11700486
2	mix B11 + B15	Waterbodem (AS3000)	11700487

Q: door RvA geaccrediteerde verrichting
A: AP04 erkende en geaccrediteerde verrichting
S: AS SIKB erkende en geaccrediteerde verrichting
V: VLAREL erkende verrichting
W: Waals Gewest erkende verrichting

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Analysecertificaat

Uw project/verslagnummer	20106	Certificaatnummer/Versie	2020181273/1
Uw projectnaam	Saba	Startdatum analyse	13-Nov-2020
Uw ordernummer	20106	Datum einde analyse	19-Nov-2020
Uw monsternemer	Adrie Lamore	Rapportagedatum	19-Nov-2020/16:43
		Bijlage	A,B,C
		Pagina	3/3
Projectcode	5185 - Aquifer - Project Waterbodem		

	Analyse	Eenheid	1	2
S	PCB 101	mg/kg ds	<0.0010	<0.0010
S	PCB 118	mg/kg ds	<0.0010	<0.0010
S	PCB 138	mg/kg ds	<0.0010	<0.0010
S	PCB 153	mg/kg ds	<0.0010	<0.0010
S	PCB 180	mg/kg ds	<0.0010	<0.0010
S	PCB (som 7) (factor 0,7)	mg/kg ds	0.0049 1)	0.0049 1)
	Polycyclische Aromatische Koolwaterstoffen, PAK			
S	Naftaleen	mg/kg ds	<0.050	<0.050
S	Fenanthreen	mg/kg ds	<0.050	<0.050
S	Anthraceen	mg/kg ds	<0.050	<0.050
S	Fluorantheen	mg/kg ds	<0.050	<0.050
S	Benzo(a)anthraceen	mg/kg ds	<0.050	<0.050
S	Chryseen	mg/kg ds	<0.050	<0.050
S	Benzo(k)fluorantheen	mg/kg ds	<0.050	<0.050
S	Benzo(a)pyreen	mg/kg ds	<0.050	<0.050
S	Benzo(ghi)peryleen	mg/kg ds	<0.050	<0.050
S	Indeno(123-cd)pyreen	mg/kg ds	<0.050	<0.050
S	PAK VROM (10) (factor 0,7)	mg/kg ds	0.35 1)	0.35 1)
	Overige org.-verontreinigingen			
S	Tributyltin (TBT)	mg/kg ds	<0.0098	<0.0098
S	Triphenyltin (TPhT)	mg/kg ds	<0.012	<0.012
S	Tributyltin (TBT) Sn	mg Sn/kg ds	<0.0040	<0.0040
S	Triphenyltin (TPhT) Sn	mg Sn/kg ds	<0.0040	<0.0040
S	Organotin som Sn factor 0,7	mg Sn/kg ds	0.0056 1)	0.0056 1)
S	Organotin som (factor 0,7)	mg/kg ds	0.015 1)	0.015 1)

Nr.	Uw monsteromschrijving	Opgegeven monstermatrix	Monster nr.
1	Waterbodem 1	Waterbodem (AS3000)	11700486
2	mix B11 + B15	Waterbodem (AS3000)	11700487

Q: door RvA geaccrediteerde verrichting
A: AP04 erkende en geaccrediteerde verrichting
S: AS SIKB erkende en geaccrediteerde verrichting
V: VLAREL erkende verrichting
W: Waals Gewest erkende verrichting

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Bijlage (A) met de opgegeven deelmonsterinformatie behorende bij het analysecertificaat. 2020181273/1

Monster nr. / Barcode	Uw monsteromschrijving / Boornr	Van	Tot	Uw datum monstername	Monsteromsch./Monstername ID
11700486	Waterbodem 1				
0537732713	1	0	0	13-Nov-2020 12:28	slib
0537732382	1	0	0	13-Nov-2020 12:28	slib
11700487	mix B11 + B15				
0537732704		0	0	13-Nov-2020 12:29	slib
0537732706		0	0	13-Nov-2020 12:29	slib

Bijlage (B) met opmerkingen behorende bij analysecertificaat 2020181273/1

Opmerking 1)

De toetswaarde van de som is gelijk aan de sommatie van 0,7*RG

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BTW/VAT No. NL 8043.14.883.B01

Bijlage (C) met methodeverwijzingen behorende bij analysecertificaat 2020181273/1

Analyse	Methode	Techniek	Methode referentie
Bodemkundige analyses			
Droge Stof	W0104	Gravimetrie	pb 3210-1 en NEN-EN 15934
Organische stof (gloeiverlies)	W0109	Gravimetrie	3210-2a/b en NEN 5754/EN 12879
Korrelgrootte < 2 µm (lutum) sedimentatie	W0173	Sedimentatie	pb 3210-3 en NEN 5753
Metalen			
Metalen (8) (As,Cd,Cr,Cu,Hg,Ni,Pb,Zn)	W0423	ICP-MS	pb 3210-4/3250-1 & NEN-EN-ISO 17294-2
Minerale olie			
Minerale Olie (C10-C40)	W0202	GC-FID	pb 3210-6 en NEN 6978
Organo chloorbestrijdingsmiddelen, OCB			
OCB (25)	W0262	GC-MS	pb 3220-1 en NEN 6980
OCB som AP04/AS3X	W0262	GC-MS	pb 3220-1 en NEN 6980
Polychloorbifenylen, PCB			
PCB (7)	W0262	GC-MS	pb 3210-7 en NEN 6980
Polycyclische Aromatische Koolwaterstoffen, PAK			
PAK (10) (VROM)	W0271	GC-MS	pb. 3210-5 & NEN-ISO 18287
PAK som AS3000/AP04	W0271	GC-MS	NEN-ISO 18287
Overige org.-verontreinigingen			
Organotin (TBT + TPhT)	W0268	GC-MS	pb 3260-2 en NEN-EN-ISO 23161

Nadere informatie over de toegepaste onderzoeksmethoden alsmede een classificatie van de meetonzekerheid staan vermeld in ons overzicht "Specificaties analysemethoden", versie juni 2020.

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Aquifer Advies
T.a.v. Ben den Toom
Dr. Langeveldplein 6
3361 HE SLIEDRECHT

Analysecertificaat

Datum: 18-Nov-2020

Hierbij ontvangt u de resultaten van het navolgende laboratoriumonderzoek.

Certificaatnummer/Versie	2020181283/1
Uw project/verslagnummer	20106
Uw projectnaam	Saba
Uw ordernummer	20106
Monster(s) ontvangen	13-Nov-2020

Dit certificaat mag uitsluitend in zijn geheel worden gereproduceerd.
De analyse resultaten hebben alleen betrekking op het beproefde object.

De grondmonsters worden tot 4 weken na datum ontvangst bewaard en watermonsters tot 2 weken na datum ontvangst. Zonder tegenbericht worden de monsters nadien afgevoerd.
Indien de monsters langer bewaard dienen te blijven verzoeken wij U dit exemplaar uiterlijk 1 werkdag voor afloop van de standaardbewaarperiode ondertekend aan ons te retourneren. Voor de kosten van het langer bewaren van monsters verwijzen wij naar de prijslijst.

Bewaren tot:
Datum: Naam: Handtekening:

Wij vertrouwen erop uw opdracht hiermee naar verwachting te hebben uitgevoerd, mocht U naar aanleiding van dit analysecertificaat nog vragen hebben verzoeken wij U contact op te nemen met de afdeling Verkoop en Advies.

Met vriendelijke groet,

Eurofins Analytico B.V.

Ing. A. Veldhuizen
Technical Manager

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Analysecertificaat

Uw project/verslagnummer	20106	Certificaatnummer/Versie	2020181283/1
Uw projectnaam	Saba	Startdatum analyse	13-Nov-2020
Uw ordernummer	20106	Datum einde analyse	18-Nov-2020
Uw monsternemer	Adrie Lamore	Rapportagedatum	18-Nov-2020/10:57
		Bijlage	A,C
		Pagina	1/2
Projectcode	5185 - Aquifer - Project Waterbodem		

	Analyse	Eenheid	1
	Bodemkundige analyses		
Q	Droge stof	% (m/m)	96.4
Q	Organische stof	% (m/m) ds	1.0
Q	Gloeirest	% (m/m) ds	99
Q	Korrelgrootte < 2 µm (Lutum)	% (m/m) ds	<2.0
	Metalen		
Q	Barium (Ba)	mg/kg ds	16
Q	Cadmium (Cd)	mg/kg ds	<0.40
Q	Kobalt (Co)	mg/kg ds	<5.0
Q	Koper (Cu)	mg/kg ds	18
Q	Kwik (Hg)	mg/kg ds	<0.10
Q	Molybdeen (Mo)	mg/kg ds	<1.5
Q	Nikkel (Ni)	mg/kg ds	5.2
Q	Lood (Pb)	mg/kg ds	<10
Q	Zink (Zn)	mg/kg ds	17
	Minerale olie		
	Minerale olie (C10-C12)	mg/kg ds	<3.0
	Minerale olie (C12-C16)	mg/kg ds	<5.0
	Minerale olie (C16-C21)	mg/kg ds	<6.0
	Minerale olie (C21-C30)	mg/kg ds	<12
	Minerale olie (C30-C35)	mg/kg ds	<6.0
	Minerale olie (C35-C40)	mg/kg ds	<6.0
Q	Minerale olie totaal (C10-C40)	mg/kg ds	<38
	Somparameter organohalogeen verbindingen		
Q	EOX	mg/kg ds	<0.10
	Polychloorbifenylen, PCB		
Q	PCB 28	mg/kg ds	<0.0010
Q	PCB 52	mg/kg ds	<0.0010
Q	PCB 101	mg/kg ds	<0.0010
Q	PCB 118	mg/kg ds	<0.0010

Nr.	Uw monsteromschrijving	Opgegeven monstermatrix	Monster nr.
1	Surface land	Grond / sediment	11700511

Q: door RvA geaccrediteerde verrichting
A: AP04 erkende en geaccrediteerde verrichting
S: AS SIKB erkende en geaccrediteerde verrichting
V: VLAREL erkende verrichting
W: Waals Gewest erkende verrichting

Analysecertificaat

Uw project/verslagnummer	20106	Certificaatnummer/Versie	2020181283/1
Uw projectnaam	Saba	Startdatum analyse	13-Nov-2020
Uw ordernummer	20106	Datum einde analyse	18-Nov-2020
Uw monsternemer	Adrie Lamore	Rapportagedatum	18-Nov-2020/10:57
		Bijlage	A,C
		Pagina	2/2
Projectcode	5185 - Aquifer - Project Waterbodem		

	Analyse	Eenheid	1
Q	PCB 138	mg/kg ds	<0.0010
Q	PCB 153	mg/kg ds	<0.0010
Q	PCB 180	mg/kg ds	<0.0010
Q	PCB (som 7)	mg/kg ds	<0.0070
	Polycyclische Aromatische Koolwaterstoffen, PAK		
Q	Naftaleen	mg/kg ds	<0.050
Q	Fenanthreen	mg/kg ds	<0.050
Q	Anthraceen	mg/kg ds	<0.050
Q	Fluorantheen	mg/kg ds	<0.050
Q	Benzo(a)anthraceen	mg/kg ds	<0.050
Q	Chryseen	mg/kg ds	<0.050
Q	Benzo(k)fluorantheen	mg/kg ds	<0.050
Q	Benzo(a)pyreen	mg/kg ds	<0.050
Q	Benzo(ghi)peryleen	mg/kg ds	<0.050
Q	Indeno(123-cd)pyreen	mg/kg ds	<0.050
Q	PAK Totaal VROM (10)	mg/kg ds	<0.50

Nr.	Uw monsteromschrijving	Opgegeven monstermatrix	Monster nr.
1	Surface land	Grond / sediment	11700511

Q: door RvA geaccrediteerde verrichting
A: AP04 erkende en geaccrediteerde verrichting
S: AS SIKB erkende en geaccrediteerde verrichting
V: VLAREL erkende verrichting
W: Waals Gewest erkende verrichting

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Bijlage (A) met de opgegeven deelmonsterinformatie behorende bij het analysecertificaat. 2020181283/1

Monster nr.	Uw monsteromschrijving				
Barcode	Boornr	Van	Tot	Uw datum monstername	Monsteromsch./Monstername ID
11700511	Surface land				
0537732398		0	0	13-Nov-2020 12:38	

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Bijlage (C) met methodeverwijzingen behorende bij analysecertificaat 2020181283/1

Analyse	Methode	Techniek	Methode referentie
Bodemkundige analyses			
Droge Stof	W0104	Gravimetrie	NEN-EN 15934 en CMA 2/II/A.1
Organische stof (gloeiverlies)	W0109	Gravimetrie	NEN 5754
Korrelgrootte < 2 µm (lutum)	W0171	Sedimentatie	NEN 5753
Metalen			
Barium (Ba)	W0423	ICP-MS	NEN-EN-ISO 17294-2
Cadmium (Cd)	W0423	ICP-MS	NEN-EN-ISO 17294-2
Kobalt (Co)	W0423	ICP-MS	NEN-EN-ISO 17294-2
Koper (Cu)	W0423	ICP-MS	NEN-EN-ISO 17294-2
Kwik (Hg)	W0423	ICP-MS	NEN-EN-ISO 17294-2
Molybdeen (Mo)	W0423	ICP-MS	NEN-EN-ISO 17294-2
Nikkel (Ni)	W0423	ICP-MS	NEN-EN-ISO 17294-2
Lood (Pb)	W0423	ICP-MS	NEN-EN-ISO 17294-2
Zink (Zn)	W0423	ICP-MS	NEN-EN-ISO 17294-2
Minerale olie			
Minerale Olie (C10-C40)	W0202	GC-FID	NEN-EN-ISO 16703
Somparameter organohalogeen verbindingen			
EOX	W0351	Microcoulometrie	Eigen methode
Polychloorbifenylen, PCB			
PCB (7)	W0271	GC-MS	NEN 6980
Polycyclische Aromatische Koolwaterstoffen, PAK			
PAK (10) (VROM)	W0271	GC-MS	NEN-ISO 18287

Nadere informatie over de toegepaste onderzoeksmethoden alsmede een classificatie van de meetonzekerheid staan vermeld in ons overzicht "Specificaties analysemethoden", versie juni 2020.

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BIC: BNPANL2A
KvK/CoC No. 09088623
BTW/VAT No. NL 8043.14.883.B01

BoToVa T1 Beoordeling kwaliteit van grond en bagger bij toepassing op of in de landbod

Uw projectnummer	20106
Projectnaam	Saba
Ordernummer	20106
Datum monstername	13-11-2020
Monsternemer	Adrie Lamore
Certificaatnummer	2020181283
Startdatum	13-11-2020
Rapportagedatum	18-11-2020

Analyse	Eenheid	1	Oordeel
Bodemtype correctie			
Organische stof		1	
Korrelgrootte < 2 µm (Lutum)		2	
Bodemkundige analyses			
Droge stof	% (m/m)	96,4	
Organische stof	% (m/m) ds	1	
Gloeirest	% (m/m) ds	99	
Korrelgrootte < 2 µm (Lutum)	% (m/m) ds	<2,0	
Metalen			
Barium (Ba)	mg/kg ds	16	
Cadmium (Cd)	mg/kg ds	<0,40	<= AW
Kobalt (Co)	mg/kg ds	<5,0	<= AW
Koper (Cu)	mg/kg ds	18	<= AW
Kwik (Hg)	mg/kg ds	<0,10	<= AW
Molybdeen (Mo)	mg/kg ds	<1,5	<= AW
Nikkel (Ni)	mg/kg ds	5,2	<= AW
Lood (Pb)	mg/kg ds	<10	<= AW
Zink (Zn)	mg/kg ds	17	<= AW
Minerale olie			
Minerale olie (C10-C12)	mg/kg ds	<3,0	
Minerale olie (C12-C16)	mg/kg ds	<5,0	
Minerale olie (C16-C21)	mg/kg ds	<6,0	
Minerale olie (C21-C30)	mg/kg ds	<12	
Minerale olie (C30-C35)	mg/kg ds	<6,0	
Minerale olie (C35-C40)	mg/kg ds	<6,0	
Minerale olie totaal (C10-C40)	mg/kg ds	<38	<= AW
Somparameter organohalogeen verbindingen			
EOX	mg/kg ds	<0,10	
Polychloorbifenylen, PCB			
PCB 28	mg/kg ds	<0,0010	
PCB 52	mg/kg ds	<0,0010	
PCB 101	mg/kg ds	<0,0010	
PCB 118	mg/kg ds	<0,0010	
PCB 138	mg/kg ds	<0,0010	
PCB 153	mg/kg ds	<0,0010	
PCB 180	mg/kg ds	<0,0010	
PCB (som 7)	mg/kg ds	<0,0070	<= AW
Polycyclische Aromatische Koolwaterstoffen, PAK			
Naftaleen	mg/kg ds	<0,050	
Fenanthreen	mg/kg ds	<0,050	
Anthraceen	mg/kg ds	<0,050	
Fluorantheen	mg/kg ds	<0,050	
Benzo(a)anthraceen	mg/kg ds	<0,050	
Chryseen	mg/kg ds	<0,050	
Benzo(k)fluorantheen	mg/kg ds	<0,050	
Benzo(a)pyreen	mg/kg ds	<0,050	
Benzo(ghi)peryleen	mg/kg ds	<0,050	
Indeno(123-cd)pyreen	mg/kg ds	<0,050	
PAK Totaal VROM (10)	mg/kg ds	<0,50	<= AW

Legenda

Nr.	Analytico-nr	Monster	Oordeel
1	11700511	Surface land	Altijd toepasbaar

Verklaring van de gebruikte tekens:

<= AW	kleiner dan of gelijk aan de Achtergrondwaarde
Ind.	klasse industrie

Deze toetsing is m.b.v. BoToVa uitgevoerd.

Zie voor info: http://www.rwsleefomgeving.nl/onderwerpen/bodem-ondergrond/bbk/instrumenten/botova/

BoToVa T3 Beoordeling kwaliteit van baggerspecie en ontvangende bodem of oever bij toepassen in een oppervlaktewaterlichaam

Uw projectnummer	20106
Projectnaam	Saba
Ordernummer	20106
Datum monstername	13-11-2020
Monsternemer	Adrie Lamore
Certificaatnummer	2020181273
Startdatum	13-11-2020
Rapportagedatum	19-11-2020

Analyse	Eenheid	1	Oordeel	2	Oordeel
Bodemtype correctie					
Organische stof					
Korrelgrootte < 2 µm, gravimetrisch					
Bodemkundige analyses					
Droge stof	% (m/m)	81,9		75,5	
Organische stof	% (m/m) ds	1,7		1,2	
Gloeirest	% (m/m) ds				
Korrelgrootte < 2 µm, gravimetrisch	% (m/m) ds	1,4		1,4	
Metalen					
Arseen (As)	mg/kg ds	4,892	<= AW	4,892	<= AW
Cadmium (Cd)	mg/kg ds	0,241	<= AW	0,241	<= AW
Chroom (Cr)	mg/kg ds	29,63	<= AW	27,78	<= AW
Koper (Cu)	mg/kg ds	24,83	<= AW	22,76	<= AW
Kwik (Hg)	mg/kg ds	0,05029	<= AW	0,05029	<= AW
Nikkel (Ni)	mg/kg ds	37,92	A	24,79	<= AW
Lood (Pb)	mg/kg ds	11,02	<= AW	11,02	<= AW
Zink (Zn)	mg/kg ds	49,83	<= AW	52,2	<= AW
Minerale olie					
Minerale olie (C10-C12)	mg/kg ds	10,5		10,5	
Minerale olie (C12-C16)	mg/kg ds	17,5		17,5	
Minerale olie (C16-C21)	mg/kg ds	17,5		17,5	
Minerale olie (C21-C30)	mg/kg ds	38,5		38,5	
Minerale olie (C30-C35)	mg/kg ds	17,5		17,5	
Minerale olie (C35-C40)	mg/kg ds	21		21	
Minerale olie totaal (C10-C40)	mg/kg ds	122,5	<= AW	122,5	<= AW
Organo chloorbestrijdingsmiddelen, OCB					
alfa-HCH	mg/kg ds	0,0035	<= AW	0,0035	<= AW
beta-HCH	mg/kg ds	0,0035	<= AW	0,0035	<= AW
gamma-HCH	mg/kg ds	0,0035	<= AW	0,0035	<= AW
delta-HCH	mg/kg ds	0,0035		0,0035	
Hexachloorbenzeen	mg/kg ds	0,0035	<= AW	0,0035	<= AW
Heptachloor	mg/kg ds	0,0035	<= AW	0,0035	<= AW
Heptachloorepoxide(cis- of A)	mg/kg ds	0,0035		0,0035	
Heptachloorepoxide(trans- of B)	mg/kg ds	0,0035		0,0035	
Hexachloorbutadieen	mg/kg ds	0,0035	<= AW	0,0035	<= AW
Aldrin	mg/kg ds	0,0035	<= AW	0,0035	<= AW
Dieldrin	mg/kg ds	0,0035	<= AW	0,0035	<= AW
Endrin	mg/kg ds	0,0035	<= AW	0,0035	<= AW
Isodrin	mg/kg ds	0,0035	<= AW	0,0035	<= AW
Telodrin	mg/kg ds	0,0035	<= AW	0,0035	<= AW
alfa-Endosulfan	mg/kg ds	0,0035	<= AW	0,0035	<= AW
beta-Endosulfan	mg/kg ds	0,0035		0,0035	
Endosulfansulfaat	mg/kg ds	0,007		0,007	
alfa-Chloordaan	mg/kg ds	0,0035		0,0035	
gamma-Chloordaan	mg/kg ds	0,0035		0,0035	
o,p'-DDT	mg/kg ds	0,0035		0,0035	
p,p'-DDT	mg/kg ds	0,0035		0,0035	
o,p'-DDE	mg/kg ds	0,0035		0,0035	
p,p'-DDE	mg/kg ds	0,0035		0,0035	
o,p'-DDD	mg/kg ds	0,0035		0,0035	
p,p'-DDD	mg/kg ds	0,0035		0,0035	
HCH (som) (factor 0,7)	mg/kg ds	0,014	<= AW	0,014	<= AW
Drins (som) (factor 0,7)	mg/kg ds	0,0105	<= AW	0,0105	<= AW
Heptachloorepoxide (som) (factor 0,7)	mg/kg ds	0,007	<= AW	0,007	<= AW
DDD (som) (factor 0,7)	mg/kg ds				
DDE (som) (factor 0,7)	mg/kg ds				
DDT (som) (factor 0,7)	mg/kg ds				
DDX (som) (factor 0,7)	mg/kg ds	0,021	<= AW	0,021	<= AW
Chloordaan (som) (factor 0,7)	mg/kg ds	0,007	<= AW	0,007	<= AW
OCB (som) LB (factor 0,7)	mg/kg ds				
OCB (som) WB (factor 0,7)	mg/kg ds	0,084	<= AW	0,084	<= AW
Polychloorbifenylen, PCB					
PCB 28	mg/kg ds	0,0035	<= AW	0,0035	<= AW
PCB 52	mg/kg ds	0,0035	<= AW	0,0035	<= AW
PCB 101	mg/kg ds	0,0035	<= AW	0,0035	<= AW
PCB 118	mg/kg ds	0,0035	<= AW	0,0035	<= AW
PCB 138	mg/kg ds	0,0035	<= AW	0,0035	<= AW
PCB 153	mg/kg ds	0,0035	<= AW	0,0035	<= AW
PCB 180	mg/kg ds	0,0035	<= AW	0,0035	<= AW
PCB (som 7) (factor 0,7)	mg/kg ds	0,0245	<= AW	0,0245	<= AW
Polycyclische Aromatische Koolwaterstoffen, PAK					
Naftaleen	mg/kg ds	0,035		0,035	
Fenanthreen	mg/kg ds	0,035		0,035	
Anthraceen	mg/kg ds	0,035		0,035	
Fluorantheen	mg/kg ds	0,035		0,035	
Benzo(a)anthraceen	mg/kg ds	0,035		0,035	
Chryseen	mg/kg ds	0,035		0,035	
Benzo(k)fluorantheen	mg/kg ds	0,035		0,035	
Benzo(a)pyreen	mg/kg ds	0,035		0,035	
Benzo(ghi)peryleen	mg/kg ds	0,035		0,035	
Indeno(123-cd)pyreen	mg/kg ds	0,035		0,035	
PAK VROM (10) (factor 0,7)	mg/kg ds	0,35	<= AW	0,35	<= AW
Overige org.-verontreinigingen					
Tributyltin (TBT)	mg/kg ds				
Triphenyltin (TPhT)	mg/kg ds				
Tributyltin (TBT) Sn	mg Sn/kg ds	0,014	<= AW	0,014	<= AW
Triphenyltin (TPhT) Sn	mg Sn/kg ds	0,014		0,014	
Organotin som Sn factor 0,7	mg Sn/kg ds	0,028	<= AW	0,028	<= AW
Organotin som (factor 0,7)	mg/kg ds	0,07546	<= AW	0,07546	<= AW

Legenda

Nr.	Analytico-nr	Monster	Oordeel
1	11700486	Waterbodem 1	Altijd toepasbaar
2	11700487	mix B11 + B15	Altijd toepasbaar

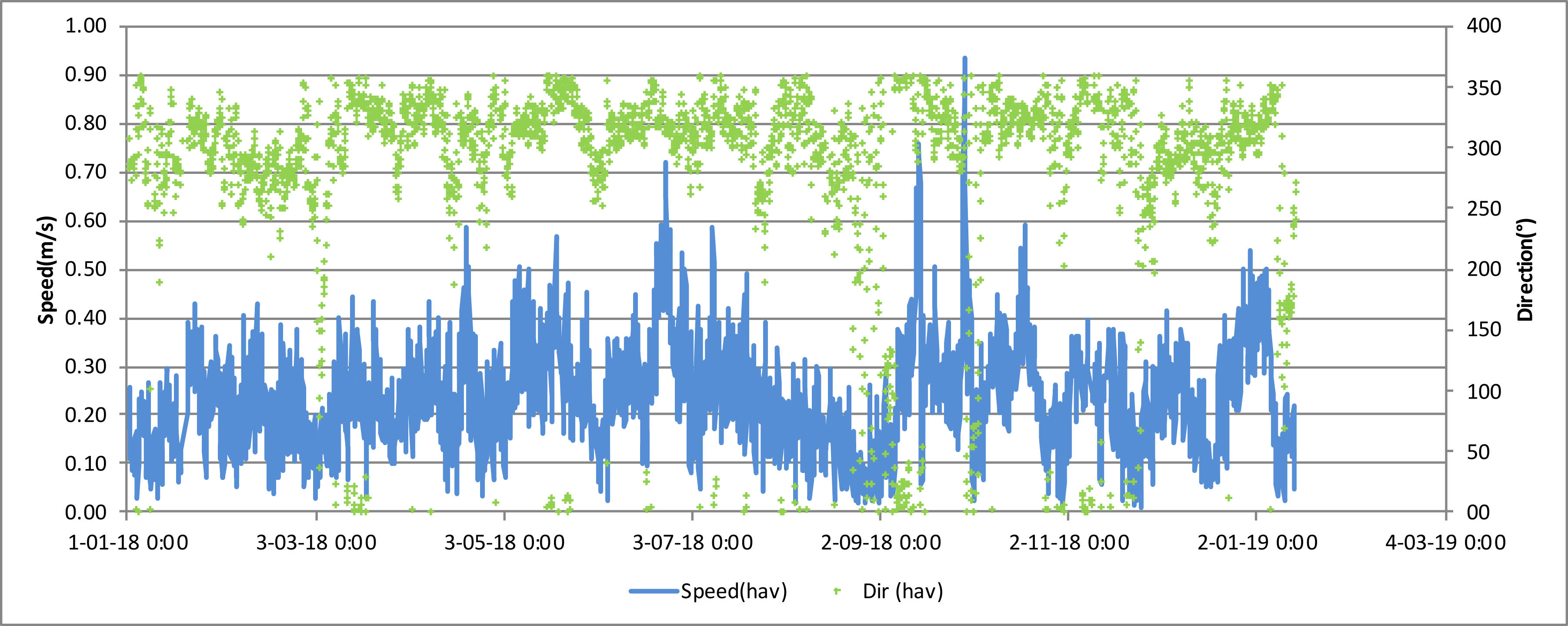
Verklaring van de gebruikte tekens:

<= AW	kleiner dan of gelijk aan de Achtergrondwaarde
A	Kwaliteitsklasse A
B	Kwaliteitsklasse B

Deze toetsing is m.b.v. BoToVa uitgevoerd.

Zie voor info: http://www.rwsleefomgeving.nl/onderwerpen/bodem-ondergrond/bbk/instrumenten/botova/

Annex 5: Hycom data (2018)


1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Speed(m/s)
400
350
300
250
200
150
100
50
00
Direction(°)
1-01-18 0:00
3-03-18 0:00
3-05-18 0:00
3-07-18 0:00
2-09-18 0:00
2-11-18 0:00
2-01-19 0:00
4-03-19 0:00
Speed(hav)
Dir (hav)

Annex 6: Wave data 1979-2018

Annex 6: Wave data 1979-2018

Count of Hs (m)	Column Labels												
Row Labels	**jan**	**feb**	**mrt**	**apr**	**mei**	**jun**	**jul**	**aug**	**sep**	**okt**	**nov**	**dec**	**Grand Total**
0-0.5	0.01%		0.16%	0.61%	1.22%	0.81%	0.73%	1.28%	2.91%	1.54%	0.12%		0.79%
0.5-1	16.10%	14.22%	22.42%	36.62%	44.46%	36.03%	31.64%	47.42%	55.81%	55.59%	30.33%	16.07%	33.98%
1-1.5	41.84%	47.26%	50.40%	49.46%	49.12%	56.02%	56.51%	42.82%	33.02%	34.22%	48.26%	50.71%	46.61%
1.5-2	32.67%	30.15%	21.70%	11.74%	5.14%	6.90%	10.11%	6.94%	5.95%	7.23%	17.26%	26.36%	15.13%
2-2.5	7.98%	7.06%	4.27%	1.22%	0.06%	0.25%	0.87%	0.94%	0.99%	1.09%	3.10%	5.83%	2.79%
2.5-3	1.17%	1.18%	0.83%	0.29%			0.11%	0.26%	0.47%	0.27%	0.59%	0.91%	0.50%
3-3.5	0.20%	0.09%	0.22%	0.05%			0.02%	0.11%	0.31%	0.02%	0.10%	0.07%	0.10%
3.5-4	0.04%	0.04%					0.01%	0.06%	0.11%		0.06%	0.05%	0.03%
4-4.5								0.04%	0.12%	0.01%	0.08%		0.02%
4.5-5								0.04%	0.11%		0.02%		0.01%
5-5.5								0.06%	0.06%	0.02%	0.01%		0.01%
5.5-6								0.01%	0.04%				0.00%
6-6.5								0.02%	0.02%		0.01%		0.00%
6.5-7									0.03%		0.01%		0.00%
7-7.5										0.01%	0.01%		0.00%
7.5-8											0.02%		0.00%
8-8.5									0.01%				0.00%
10-10.5									0.01%				0.00%
11-11.5									0.01%				0.00%
Grand Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Annex 7: Results of the Reef Health Index for 20 sites on Saba (Van der Vlugt, 2016)

Annex 7: Assessment according to Reef Health Index for 20 sites on Saba

Data 2015 (Van der Vlugt, 2016) and 2016 (Hildebrand, 2017)

Scale: 1 = Critical, 2 = Poor, 3 = Fair, 4 = Good, 5 = Very Good

Dive sites	2016		2015			2016		2015	
	Coral cover in %	RHI	Coral cover in %	RHI		*Macro Algae cover in %	RHI	*Macro Algae cover in %	RHI
Wells Bay	4.6	1	4.3	1		19.0	2	5.4	3
Fort Bay	3.7	1	3.5	1		0.4	5	0.7	5
Greer Gut	3.6	1	2.9	1		27.0	1	21.3	2
Big Rock Market	4.8	1	2.5	1		41.3	1	10.8	3
Giles Quarter Shallow	3.8	1	2.0	1		20.9	2	23.1	2
Hole In The Corner	7.3	2	6.8	2		38.5	1	14.2	2
Core Gut	5.6	2	3.7	1		36.6	1	18.7	2
Green Island	2.8	1	6.5	2		16.2	2	11.2	3
David's Drop Off	6.3	2	5.9	2		34.0	1	20.2	2
Diamond Rock	**14.9	3	6.9	2		5.9	3	6.2	3
Man of War Shoals	9.9	2	8.3	2		6.1	3	3.9	4
Custom's House	12.3	3	7.9	2		45.0	1	20.0	2
Porites Point	4.7	1	4.7	1		25.2	1	29.1	1
Babylon	9.9	2	6.5	2		23.5	2	11.6	3
Ladder Labyrinth	5.5	2	5.8	2		16.5	2	17.2	2
Ladder Labyrinth 2	7.1	2	6.5	2		30.4	1	22.3	2
Hot Springs	4.2	1	2.5	1		3.1	4	2.4	4
Tent Reef	13.2	3	9.8	2		0.5	5	1.7	4
Tent Reef Deep	2.9	1	7.7	2		4.2	4	4.9	4
Torrens Point	5.3	2	4.9	1		18.0	2	22.1	2
	Total 2016	**RHI**	**Total 2015**	**RHI**		**Total 2016**	**RHI**	**Total 2015**	**RHI**
	6.6	**2**	**5.5**	**2**		**20.6**	**2**	**13.4**	**2**
	Fished sites	**RHI**	**Fished sites**	**RHI**		**Fished sites**	**RHI**	**Fished sites**	**RHI**
	4.8	**1**	**4.3**	**1**		**25.1**	**1**	**14.8**	**2**
	Unfished sites	**RHI**	**Unfished sites**	**RHI**		**Unfished sites**	**RHI**	**Unfished sites**	**RHI**
	8.5	**2**	**6.7**	**2**		**16.0**	**2**	**11.9**	**3**

*Turf excluded from Macro algae, as RHI is based on fleshy Macro algae

**12, 9% of the coral cover at Diamond Rock consists of Firecoral (Millepora spp.)

Key Herbivorous Fish (g/100 m^2)					Key Commercial Fish (g/100 m^2)			
Total 2016	**RHI**	**Total 2015**	**RHI**		**Total 2016**	**RHI**	**Total 2015**	**RHI**
3741	**5**	**1954**	**3**		**1242**	**3**	**1319**	**4**
Fished sites	**RHI**	**Fished sites**	**RHI**		**Fished sites**	**RHI**	**Fished sites**	**RHI**
4480	**5**	**2251**	**3**		**845**	**3**	**488**	**2**
Unfished sites	**RHI**	**Unfished Sites**	**RHI**		**Unfished sites**	**RHI**	**Unfished sites**	**RHI**
3002	**4**	**1656**	**2**		**1640**	**4**	**2150**	**5**

Mean total RHI 2016	Mean total RHI 2015
3	**2.75**
Mean total RHI fished sites	**Mean total RHI fished sites**
2.5	**2**
Mean total RHI unfished sites	**Mean total RHI unfished sites**
3	**3**

Annex 8: Mitigation of underwater noise in relation to marine mammals (literature study)

The effects, consequences & mitigation of sound from impact and vibratory driven piles on marine mammals

[redacted]

02/26/2019

Ecovision N.V.

Table of content

Sound stimuli in marine mammals

Marine mammals can produce and hear a variety of sounds. They use it to communicate, avoid predators, detect and capture prey, mating, orientation, and navigation (Wartzok and ketten 1999). According to the marine mammal commission report to congress from March 2007, marine mammals have adapted to a variety of natural sounds, and these adaptations may allow them to become accustomed to the presence of many anthropogenic sounds. However, an introduced sound can still exceed the adaptive capacity of marine mammals, and in turn can cause physical injury or physiological reactions, behavioral responses, masking, and other effects. This disturbance can pose a threat to individual animals and their population (Marine Mammal Commission, 2007). To further elaborate, a behavioral response can be triggered at a certain level defined as the detection threshold. Depending on variables such as frequency, duration, and temporal pattern during a sound, or age, sex, habitat, previous exposure and behavioral state in an animal, can determine if an animal responds to a detected sound (Wartzok et al. 2004). An example of behavioral response is when a sea mammal relocates due to higher levels of sound, or changes their swim pattern and vocal intensity (Olesiuk et al. 2002). A behavioral response due to high sound levels can also cause a change in reproduction and feeding pattern, and in worst case scenario death (Richardson et al. 1995). Certain anthropogenic sound has been shown to be lethal to sea mammals; such was the case of an incidence when 37 whales of 3 different species beached themselves on the shores of North Carolina in January 2005, when the US Navy used a powerful sonar (Kaufman, 2005). Aside from change in behavioral responses, masking can also interfere with the regular behavior of a marine mate call, (2) mother-offspring bonding and recognition, (3) foraging if animals cannot detect prey and communicate to hunt, and (4) survival if an animal cannot detect threats such as predators or vessels. However, marine mammals have developed ways to overcome certain masking by changing the way they communicate. By changing the level, temporal pattern, or shifting the frequency of their vocals. In certain cases they can be used to overcome masking produced by anthropogenic noise (Au and Moor, 1984). Another effect that sounds exposure can have on marine mammals is the physiological effects. The auditory system is the most sensitive to sounds exposure, but also non-auditory systems can get affected. Stress and tissue injury are other physiological effects that sounds exposure can cause. Exposing beluga whales to intense sound levels increases levels of stress markers in their blood, while a Blanc test did not show similar levels of stress (Thomas et al. 1990). Thus exposure of high intensity sound on marine mammals may cause a temporary threshold shift, or a temporary loss of hearing sensitivity (Finneran et al. 2005). While within limits it can still be reversible, it still has the potential to increase an animal's vulnerability to predators, and reduces its communication and foraging efficiency. While temporary thresholds might be reversible, permanent thresholds can also occur when marine mammals are exposed to very intense sounds causing a physical injury (Clark 1991). Such physical injury can cause a permanent threshold shift due to the loss of sensory cells and nerve fibers. Such injuries have been observed in humpback whales that were exposed to pressure waves from explosions (Ketten et al. 1993). Scientist also made the hypothesis that sounds can cause physical injuries such as tissue shear, acoustic resonance, or acoustically made bubble growth or mico-bubbles (Houser et al. 2001). Lastly sound may also have an indirect effect on marine mammals through ecological parameters. A study on these indirect effects showed that seismic activity may cause a decrease in the number of fish in the survey region (skalski et al. 1992). This would have an indirect effect on the foraging efficiency of marine mammals, limiting their growth, condition, reproduction and survival.

Pile driving sound effects on marine mammals

Pile driving is a method used for installing support elements called piles to aid in the construction of large structures in shallow marine environments. This can be done by using the impact or vibrational pile driving method (Pile driving 2019). In the case of impact pile driving, it can produce intense, broadband impulsive sounds that can travel for many kilometers. Within 10 meters of the sound source, pressure levels (SPL) can range up to 220 dB Peak. However, it can vary substantially depending on the hammer size, power of hammer, pile material, Diameter of pile and composition of the seafloor (Pile driving 2019).

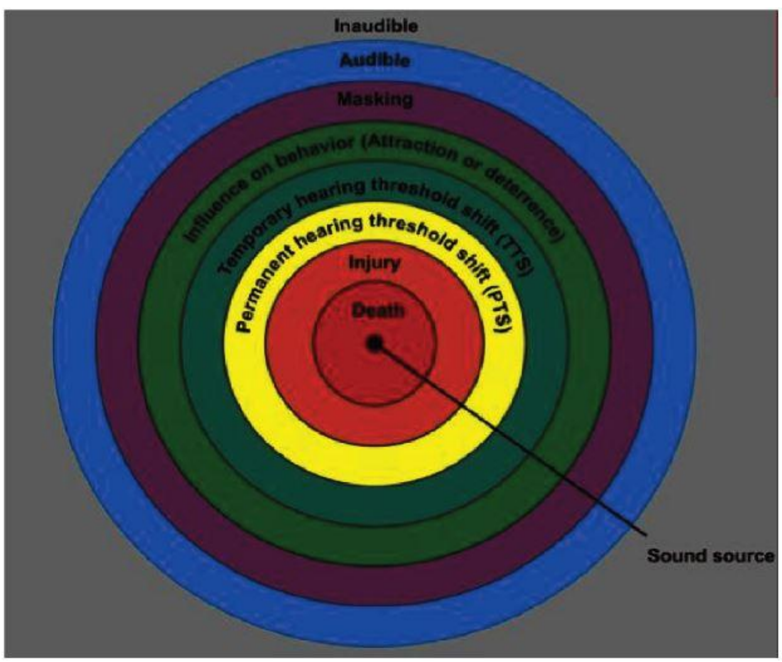


Figure 1. Range of effects of a sounds source on marine mammals (Prins, Twisk, Van den Heuvel-Greve, Troost, & Van Beek, 2008)

According to figure 1, underwater noise levels can be categorized at different ranges. The closer the organism is to the source, the higher the probability that it might die (Nedwell, Turnpenny, Langworthy, & Edwards, 2003). The region marked as red can result in death or injury, which is the closest to the sound source (distance is dependent on the intensity of the sound). Outside of the red zone there is the permanent hearing threshold shift (PTS) and the temporary hearing threshold shift (TTS). PTS and TTS are term used to describe noise-induced hearing loss. For example, TTS (green) can be explained by temporary hearing loss experienced by humans when a firecracker goes off nearby. As for PTS (yellow), this is when permanent damage is done to the hearing threshold (Saleem 2011). Table 1 shows the hearing thresholds of two animal orders.

Table 1: Threshold Shift levels for certain mairne mammals (Nehls, Betke, Eckelmann, & Ros, 2007)

Animal Order	Layman Name	Temporary Threshold Shift (TTS)		Permanent Threshold Shift (PTS)	
Cetaceans	Whales/Dolphins and Porpoises etc.	183 dB SEL pulses	224 dB peak pressure	215 dB SEL	230 dB peak pressure
Pinnipeds	Walrus/Seals	163 dB SEL pulses	204 dB peak pressure		210 dB peak pressure

Considering that impact pile driving pressure levels can range up to 220 dB or more depending on the equipment and soil, it is apparent that it can bring harm to marine mammals in its vicinity.

Impact compared to vibratory driven piles

Hydraulic impact pile driving is not the only method of pile driving there is. Another technique used is the vibratory driven pile driving, which is a technique that places piles into the soil by small longitudinal vibration motion at certain frequency and amplitude (Deep Foundations Institute 2015). According to Zohaib Saleem, with the correct ground conditions, vibratory pile driving can have several advantages over hydraulic impact pile drivers. According to him the advantages are as follows (Saleem 2011):

- There were no diameter limitations. Meaning that vibratory hammers are able to be joined together to create a bigger vibrational hammer.
- The installation process is three to four times faster when compared to hydraulic impact hammering.
- Lower cost due to less energy and time to install the piles
- The vibratory method is not only used to install piles, but it can also be used to remove or re-align piles.
- Low noise emissions. This is an important factor to reduce injuries/death caused to marine mammals. When compared to hydraulic impact pile driving the noise is greatly reduced. The noise reduction can be approximately 15-20 dB and can

be more depending on the type of pile and soil conditions. Figure 2 shows two noise spectrum comparing impact hammer vs vibratory hammer.

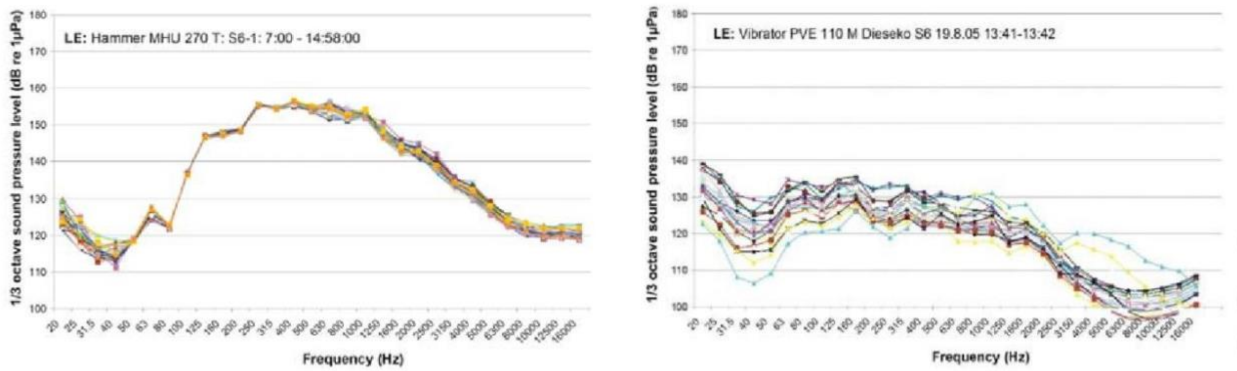


Figure 2: Noise Spectrum of a Impact hammer (Left) vs Vibrational hammer (right) (Elmer, Neumann, Gabriel, Betke, & Glahn, 2007)

Even though vibratory pile driving has advantages it has to be noted that a disadvantage is not being able to control the reliability of the bearing capacity. In permanent applications vibro piles are struck with an impact hammer to check the bearing capacity, which reduces the economic and environmental benefits of using vibratory drivers (Deep Foundations Institute 2015).

Mitigation

Pile driving as mentioned before can create high intensity sound levels and is a common method used for placing piles in the soil. This means that certain steps need to be taken to prevent or reduce damages done to the environment, in particular the marine organisms. If the hydraulic impact pile driver is being used, then there are three methods that could be used to reduce the noise. The first one is changing the pile-toe shape. The pile-toe is the first point of contact with the seabed, meaning that the energy is directly transferred to the ground at this origin. The shape of the tip can have an influence on the energy needed during installation (think about a nail). Having beveled piles could require 20% less-pile head energy, 27% less hammer kinetic energy per unit length, and can require 29% less blows to reach the same depth as a regular pile (Raines, Ugaz, & O'neil,1992). Having less blows can reduce the amount of noise transmitted into the area. Secondly, a contact damper can be used between the pile and the hammer to absorb some of the energy, making the sound amplitude lower. However, this method requires more blows to achieve the desired depth and would only be feasible if the sound reduction is significantly different (Erkel, 2011). Lastly, changing the parameter for the pile stroke can reduce the noise generated. This can be done by prolonging the contact time of the hammer, in which would reduce the amplitude of the pile vibration and in turn reduce the noise (Nehls, Betke, Eckelmann, & Ros, 2007). This method does not require any change in the installation technique. The sound reduction of this method is theoretically calculated to be around 10 dB, and with the combination of other methods such as the sound isolation/damping methods can provide a solution. Sound damping is the isolation and dampening of noise during the pile driving operation, be it hydraulic impact or vibrational pile driving. The two techniques used to achieve this are the confined bubble curtains and pile sleeves (Saleem 2011). According to Saleem, one of the greatest benefits of using these techniques is that the existing installation techniques don't need to be altered (Saleem 2011). The principle of using air bubble for noise reduction is based on a phenomenon of sound scattering and on the resonance of vibrating air bubbles. Different bubbles size dampens different sound in the spectrum, as can be seen in figure 3.

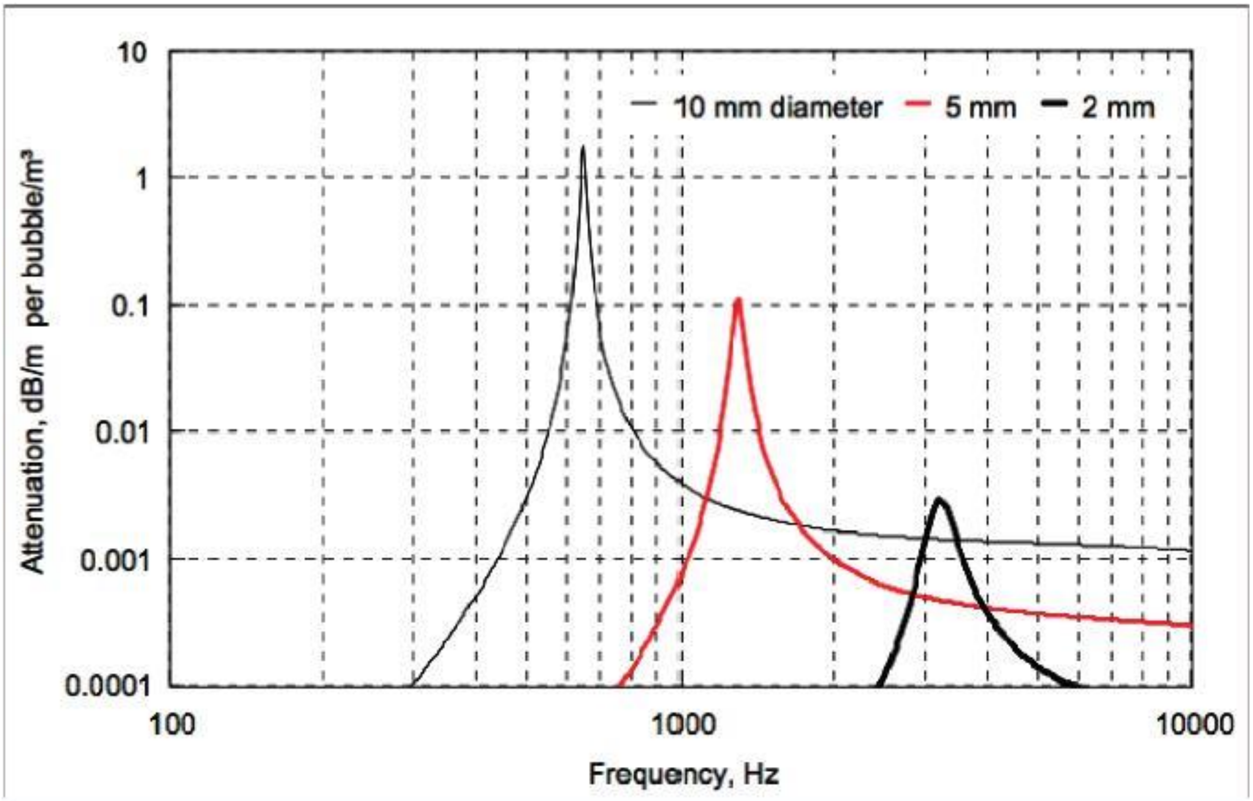


Figure 3: Sound reduction for various bubble sizes in the sound spectrum (Nehls, Betke, Eckelmann, & Ross, 2007)

As shown, the bigger the bubble diameter, the wider coverage it has of the spectrum. It is difficult to create larger bubbles, because the larger the bubble, the less stable it becomes and breaks up into smaller bubbles as it is traveling to the water surface (Saleem 2011). Another factor to account for is that the ocean is in constant motion, therefore the bubbles created on the sea bed will be swept by the current and the noise reduction might not occur. Therefore, using a sleeve as a confinement can contain the bubbles as seen in figure 4.

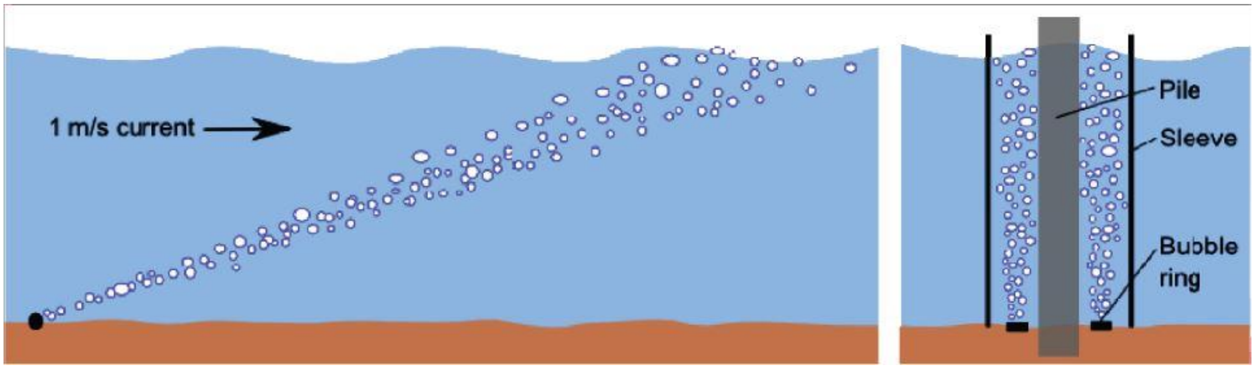


Figure 4: open bubble curtain vs confined bubble curtain (Nehls, Betke, Eckelmann, & Ros, 2007)

Aside from the bubble curtain a pile sleeve can be used, which is different from the sleeve used for the bubble curtain (which is made of a semi permeable fabric). A pile sleeve is a physical sound barrier that is placed around the source. In this case the pile sleeve encompasses the pile. The gap between the pile and the sleeve can be filled with different diameter of foam or steel, or even filled with air to reduce the noise created. This method can reduce about 25 dB, especially in the low-frequency region where reduction is needed (Erkel, 2011). Combining this method with the pile stroke parameter can create even more noise reduction.

Adjusting the equipment or methods are not the only steps that can be taken to prevent injuries on marine mammals. A protocol can be created that includes for spatial and temporal measures. This measure is a more targeted approach to limit or modify the use of a sound source. According to a report to the Congress from the Marine Mammal Commission in March,2007, Sound inducing activities can be prohibited in areas such as a critical habitat, breeding grounds, marine protected areas, migratory pathways, or where marine mammal abundance or diversity is particularly high. Or sound inducing activities can be limited temporally to avoid certain breeding or calving seasons, migratory periods or other sensitive times (Marine Mammal Commision, 2007). Another measure is the operational requirements and limitations, which is the last category of mitigation methods. According to the previous report mentioned, in this measure sound can be used as manner around the parameter to deter marine mammals to prevent them to come any closer and get injured. However, the sound emitted could cause temporary threshold shifts or attract marine mammals instead. The report also suggests creating and monitoring a safety zone around the sound source. If marine mammals are detected within or approaching the safety zone, then all operations are to be placed on hold or altered until the zone is clear of marine mammals. This approach however can be limiting, considering that marine mammals are often difficult to detect, and can decline significantly with distance from the observer, sea conditions, lighting conditions, etc. (Marine Mammal Commision, 2007).

Monitoring

Even though marine mammals monitoring can be difficult, there are three methods to aid in detection. The first one is visual monitoring, which is the most commonly used method to detect marine mammals. Observers visually scan for marine mammal outside and within the safety zone, of which are dependent on sighting conditions and sighting platform. The behavioral pattern and migration can make spotting certain mammal species harder. However, marine mammals that come closer to shore tend to aggregate in groups and can spend more time at the surface (Marine Mammal Commision, 2007). Observers can also make use of live feed underwater survey cameras to survey what occurs beneath the surface area. The second method for monitoring is the passive acoustic monitoring. This method is done by using a hydrophone (listening device) to detect if marine mammals are present based on their vocalizations or other sound producing behaviors. This system allows for the detection of marine species of a broad temporal and spatial scale (Nieukirk et al. 2004). This method is less affected by weather and sighting conditions and can increase the detection rates (Barlow and Taylor,2005). Hydrophones can also be placed on the ocean bottom to capture sounds that certain marine mammals only make when at a certain depths. However this method should be done in combination with the visual survey to validate the sound observed. And lastly, the active acoustic monitoring is used to survey the marine environment by emitting high-frequency pulses and detecting echoes objects of interest. A limiting factor is that it can produce false positives such as other biological or physical phenomenon that could echo at the same frequency as marine mammals. In addition, depending on the frequency output of the transducer, it can be another source of anthropogenic sound that may have effects on marine mammals (Marine Mammal Commision, 2007)). Just as the passive acoustic method, the active acoustic method would also be more accurate in combination with the visual survey to reduce false-positive readings.

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Annex 9: Success rates for coral relocation (*Acropora* and *Montastraea*)

Coral relocation literature

Coral relocation and restoration has been practiced over the past 40 years worldwide. The field itself has grown slowly and many different techniques have been developed and used over that time. The success of these relocations and restorations have been measured by a variety of parameters, with the most popular metrics being survival rate, mortality rate or growth rate.

These metrics should ideally be compared to control corals in a nearby location with similar conditions and environmental factors. However, many restoration projects lack appropriate standardised monitoring and reporting, so comparison can be difficult.

The proposed coral relocation for the Saba Black Rocks Harbor project is achieved using two distinct methods. The first is called direct transplantation which refers to relocating coral colonies or fragments without an intermediate nursery phase. Direct transplantation involves taking fragments from a donor site and moving them directly to a new site. The second method is called coral gardening, which refers to relocating coral fragments after an intermediate nursery phase, where fragments have been held temporarily in a nursery.

Below is a review of the current available literature on these two methods, including case studies for both species that are planned to be transplanted (*Orbicella spp.* and *Acropora palmata*)

A systematic review of all global coral restoration methods and successes was published earlier this year (Bostrom-Einarsson L. 2020). The review compiled over 4 decades worth of coral restoration techniques, data from peer-reviewed scientific literature and surveys with coral restoration practitioners.

Within the review database, 94 descriptions of direct coral transplantation found representing 20% of all records. Direct transplantation was most common in programs aimed at rescuing corals from planned construction activities that would otherwise destroy or damage the colonies (Plucer-Rosario G 1987, Thornton SL 2000, Gayle PMH 2005). **Overall, direct transplantation studies reported an average survival of 64%, with 20% of studies reporting >90% survival of transplanted corals.**

The review also highlighted, 48% of case studies involved coral gardening, where corals were raised in either field-based or land-based nurseries, depending on local conditions. Practitioners advocating the use of a coral nursery phase for reef restoration highlight improved growth and survivorship rates of fragments (with fragment survival increasing with initial size; Forrester GE 2014), compared to direct transplantation. While some projects do report high survival (>75%; Putchim L 2008) this is not echoed in the overall dataset, where **coral gardening studies exhibited an average 66% survival in the outplanting phase, compared to 64% survival in direct transplantation studies which lacked an intermediate nursery phase.**

Looking specifically at Caribbean corals, Acroporid restoration in Belize discovered unusually high survival rates of 89% for *Acropora palmata* transplants from one reef to another, after

6 years of monitoring (Carne L 2016). This success was noticeable when compared to similar efforts in the USVI that found only 3% survivorship of *A. palmata* after 12 years (Garrison and Ward 2012) or in Japan, where a 20% survival in outplanted corals was observed after four years (Omori 2011). Carne, also documented a staggering 99% survival rate for nursery-grown, out-planted *A. palmata* (December 2010- June 2016).

In comparison to Acroporid species, there are far less published studies reviewing the success of direct transplantation of *Orbicella* species. In Florida, as part of a larger review of survivorship in coral nurseries (Monty JA 2006), 5 colonies of *Orbicella faveolata* were transplanted across two coral nursery models and an 80% survival rate was reported of these colonies after 31 months. In 1997, 1 colony of *Orbicella annularis* was relocated as part of 271 other scleractinian coral colonies and a 100% survivorship was found for this colony 2 years later (Thornton SL 2000). The small amount of data available for *Orbicella* species, makes it hard to deduce any statistical relevance from this. However, if we look at Caribbean coral species with the same morphology (massive), where similar transplanting techniques would be used as for *Orbicella spp.*, Bostrom-Einarsson L. 2020 review database shows a reported survival of 71.64% for direct transplantation. This review included the following genera: Porites, Orbicella, Montastrea, Siderstrea, Diploria, Stephanocoenia, Solenastrea, Meandrina and Dichocoeania.

To ensure the greatest success for transplanting corals for the Black Rocks Harbor project a few locations should be trialled before the full transplant starts. Becker and Mueller (2001) succinctly explained, “reasons for failure [for coral transplantation] may include transport stress, inappropriate species for the restoration site, obtaining donor colonies from an incompatible habitat, poor attachment or subsequent loss in high-energy settings.”

Piloting the transplanting of a 10-15 colonies of *Orbicella spp.* across minimum of 2 locations where *Orbicella spp.* are currently found will help mitigate a few of these potential points of failure as highlighted be Becker and Mueller. The pilot would be able to highlight any factors that could currently result in coral transplanting losses (such as transport stress, poor attachment technique or unsuitable location) before the full transplant occurs.

As the *A.palmata* fragments will be held in a nursery, the transplant location testing for this species could be done at the same time as *Orbicella spp.* or once the construction of the harbor has been completed. Piloting the *A.palmata* transplanting after the construction has been completed will allow for the new seaward sides of the breakwater of the harbor to be tested as well.

Ideally, the pilot would be monitored for at least 12 months to measure the survivorship and choose the most suitable location. However, with time constraints present, monitoring of these transplanted corals should be done for as long as possible (with a minimum of 8 weeks).

Once the relocation has occurred, follow up monitoring should be compared with collected data from non-transplanted control corals nearby. This comparison can provide stronger evidence for the success of the work. This was clearly shown in Florida in 1997 when a variety of coral species were relocated from an outfall pipe (Thornton SL 2000). After 2 years post-transplantation, the success rate (number of corals still attached and alive) was 87%. In comparison, seven sites of nearby natural substrate corals had mean success rates of 83%. Highlighting that the success rate was even higher than surrounding control corals.

Success of relocation can also vary with time and an extended timeline for monitoring (2-5 years) can uncover further information about external factors affecting work. A study looking at survival rates of *A. palmata* in BVI (Forrester GE 2014) found that mortality was higher in the first year after transplanting than in subsequent years, perhaps reflecting stress from handling or failure of the attachment method. Survival also varied depending on the number of major storms that occurred that year, with lower survival rates when there were years with storms. An extended timeline of data collection can only strengthen conclusions surrounding the work carried out and also provide further explanation for positive or negative trends that may be seen.

The success of a coral relocation project can be measured in a variety of different ways. Once a standardised monitoring procedure with clear achievable metrics is decided upon, long term monitoring (5 years) and comparison to non-transplanted coral colonies is recommended to determine stronger conclusions about the success of the project.

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Annex 10: Memo on collection of runoff by weirs

MEMO

Drainage Study New Harbor Giles Quarter Saba, impact average year rainfall

Memo by:	[redacted] **/ CCM Engineering**
Date:	**revised April 15th 2021**
Subject:	**Impact of rainfall year 2017 and year 2018 on the proposed upstream dams and harbor design/coastal outlets**

Preface

With reference to drainage report CCM Engineering nr. cur2012-500 dated April 11th 2020, CCM Engineering is asked to provide a memo that considers the impact of rainfall of an under average considered year like 2018 as well as an above average considered year like 2017, on the proposed upstream dams and the planned harbor design compared to the original situation.
KNMI, the Royal Netherlands Meteorological Institute, has provided rainfall info of the years 2017 and 2018. In the data sheet of 2017 some info was missing. Assumed rainfall has been added to make the year 2017 a complete and above average rainfall year. The purpose of providing this memo is for environmental considerations.

The before mentioned report of April 2020 has the folowing starting points: Looking at the large catchment area and the steep slopes of the upstream area, two detention ponds or dams are introduced with the purpose of limiting the amount of rainwater draining towards the harbor project and towards the sea, as well as slowing down the speed of the water that would bring down a lot of eroded sand and silt material. The dams are projected in such a way to catch as much as possible upstream runoff water looking at the existing contour lines. The total detention should lead to a substantial decrease of runoff towards the sea of at least 40% (with the design storm), with purpose of preventing damage to the harbor project, less erosion coming down hill and thus protecting the coral reef.

1. Data KNMI

The two attachments show the data provided by KNMI for Saba Airport in the year 2017 and 2018.
The data show the daily rainfall on Saba Airport calculated as the sum of 10-minute measurements.
On the same sheet we extracted the periods with the highest rainfall, on the day itself as well as the day after (if applicable).

The total rainfall in 2018 is 669.5 millimeters and is considered under-average. The total rainfall in 2017 is 1118.3 millimeters and is considered above average. KNMI took over the process of collecting rainfall data from Meteo Curacao as from 2010. Meteo Curacao states a long-term average yearly rainfall (data 1971-2000) being 760.5mm. Meteo Curacao also states this number in other reports to be 1050mm, but there is no summary sheet available that backs up that number. Meteo Curacao has been asked to clarify this. For now, we assume the long-term average yearly rainfall to be 760.5mm.

2. Impact on the 2 proposed dams and the harbor area

As the dams are proposed with agreed guideline of a design shower of 180 mm per hour with a duration of 15 minutes and a return period of 10 years, the periods with lower amounts of rainfall in 2018 and 2017 are regarded to have low impact meaning the dam system will have such a capacity that overflow is not the case. The system is meant to decrease runoff with at least 40% regarding heavy rain showers.

The periods with highest rainfall in 2018 and 2017 are calculated in the Storm Analysis model to see what the results would be with respect to the 2 dams and the 2 projected rainfall outlets at the harbor area along the coastline. Also, for reason of comparison total volumes are calculated.
The daily rainfall is calculated assuming it falls in 1 hour of time. Stor-01 is the northern proposed dam, Stor-02 is the southern proposed dam. On the second day the water level in the two dams is assumed to be the level as calculated for the day before. Outfall-01 is the outfall draining towards the sea at the west side of the harbor, Outfall-02 is the outfall draining towards the sea at the east side of the harbor.

Assumed water infiltration into the soil: see report April 2020 with runoff coefficient for upstream area 0.62 and runoff coefficient for harbor area 0.96.
Assumed water infiltration and evaporation behind the dam (ponded area): 100mm per day, consisting of 90mm of infiltration plus 10mm of evaporation.

2. 1 Peak flow calculations 4 periods with highest rainfall in 2018

Period 5-Jan-2018 + 6-Jan-2018:

5-Jan-2018 / 10 mm:

- Stor-01 max water depth = 3.78m / peak inflow = 0.8 m3/s
- Max water level = 45.78m (bottom = 42m) / wear is 49m = no overflow
- Stor-02 max water depth = 0.66m / peak inflow = 0.07 m3/s
- Max water level = 28.66m (bottom = 28m) / wear is 31m = no overflow
- Out-01 = 0.04 m3/s
- Out-02 = 0.04 m3/s
- Total volume out = 266 m3

6-Jan-2018 / 5.4 mm:

- Stor-01 max water depth = 5.00m / peak inflow = 0.43 m3/s
- Max water level = 47.00m (start = 45.78m) / wear is 49m = no overflow
- Stor-02 max water depth = 0.91m (start = 28.66m) / peak inflow = 0.04 m3/s
- Max water level = 28.91m / wear is 31m = no overflow

- Out-01 = 0.02 m3/s
- Out-02 = 0.02 m3/s
- Total volume out = 144 m3

Period 27-May-2018 + 28-May-2018:

27-May-2018 / 32.9 mm:

- Stor-01 max water depth = 7.41m / peak inflow = 2.63 m3/s
- Max water level = 49.41m (bottom = 42m) / wear is 49m = overflow 2.46 m3/s
- Stor-02 max water depth = 2.53m (bottom = 28m) / peak inflow = 2.67 m3/s
- Max water level = 30.53m / wear is 31m = no overflow
- Out-01 = 0.12 m3/s
- Out-02 = 0.13 m3/s
- Total volume out = 882 m2

28-May-2018 / 0.1 mm:

- Stor-01 max water depth = 7.01m / peak inflow = 0.01 m3/s
- Max water level = 49.01m (start = 49.41m) / wear is 49m = overflow 0.01 m3/s
- Stor-02 max water depth = 2.54m / peak inflow = 0.01 m3/s
- Max water level = 30.54m (start = 30.53m) / wear is 31m = no overflow
- Out-01 = 0.0 m3/s
- Out-02 = 0.0 m3/s
- Total volume out = 0

Period 29-Aug-2018 + 30-Aug-2018:

29-Aug-2018 / 30.8 mm:

- Stor-01 max water depth = 7.37m / peak inflow = 2.46 m3/s
- Max water level = 49.37m (bottom = 42m) / wear is 49m = overflow = 2.04 m3/s
- Stor-02 max water depth = 2.03m / peak inflow = 2.22 m3/s
- Max water level = 30.03m (bottom = 28m) / wear is 31m = no overflow
- Out-01 = 0.11 m3/s
- Out-02 = 0.13 m3/s
- Total volume out = 828 m3

30-Aug-2018 / 13.5 mm:

- Stor-01 max water depth = 7.24m / peak inflow = 1.08 m3/s
- Max water level = 49.24m (start = 49m) / wear is 49m = overflow = 1.08 m3/s
- Stor-02 max water depth = 3.25m / peak inflow = 1.17 m3/s
- Max water level = 31.25m (start = 30.03m) / wear is 31m = **overflow = 1.17 m3/s**
- Out-01 = 1.22 m3/s
- Out-02 = 0.06 m3/s
- Total volume out = 2459 m3

Period 14-Sep-2018 + 15-Sep-2018:

14-Sep-2018 / 51 mm:

- Stor-01 max water depth = 7.58m / peak inflow = 4.07 m3/s
- Max water level = 49.58m (start (14d) = 47.84m) / wear is 49m = overflow = 4.07 m3/s
- Stor-02 max water depth = 3.61m / peak inflow = 4.42 m3/s
- Max water level = 31.61m (start (14d) = 29.85m) / wear is 31m = **overflow = 4.42 m3/s**
- Out-01 = 4.60 m3/s
- Out-02 = 0.21 m3/s
- Total volume out = 11498 m3

15-Sep-2018 / 1.4 mm:

- Stor-01 max water depth = 7.05m / peak inflow = 0.11 m3/s
- Max water level = 49.05m (start = 49.48)/ wear is 49m = overflow = 0.11 m3/s
- Stor-02 max water depth = 3.06m (start = 31.5) / peak inflow = 0.12 m3/s
- Max water level = 31.06m / wear is 31m = **overflow = 0.12 m3/s**
- Out-01 = 0.12 m3/s
- Out-02 = 0.01 m3/s
- Total volume out = 285 m3

2. 2 Other periods with less rainfall in 2018

The other periods in 2018 with less rainfall are assumed they would fill the two dams to a certain extent, with no overflow and consequently low peak flow on the harbor area and low peak flow towards the sea.

2. 3 Conclusions impact rainfall as was in 2018 and comparison to original

Overflow:
From above mentioned calculations with assumed rainfall as was in 2018 it is concluded that the dam system (southern dam) would only have overflow on August 30th, plus September 14th and September 15th, meaning a total of 3 times in this year. The peak overflow of September 15th is considered being very low.

Volumes of water towards the sea for a period of one year:

Calculation original situation rainfall in one year as in 2018, water towards the sea:

Rainfall x area x runoff coefficient = 0.6695 x 550.000 m2 x 0.62 = **228.300 m3**

Calculation new situation with detention ponds and rainfall as in 2018, water towards the sea:

1. highest daily rainfall periods

5 Jan	266 m3
6 Jan	144 m3
27 May	882 m3
28 May	0
29 Aug	828 m3
30 Aug	2459 m3
14 Sep	11498 m3
15 Sep	285 m3

Total 8 days 16.362 m3

2. average daily rainfall periods

Total rainfall one year = 669.5mm
Highest rainfall periods = 145.1 mm
Average daily rainfall outside higher rainfall periods = 524.4mm /357 days = 1.47 mm
Area runoff coefficient 0.62 = 37600 m2 (upstream below ponds)
Area runoff coefficient 0.96 = 4400 m2 (harbor area)

Rainfall 357 days: (0.00147 x 37600 x 0.67) + (0.00147 x 4400 x 0.96) = **44 m3/day**
44m3 x 357 = 15.708 m3

Total volume of water towards the sea with detention ponds = 16.362 + 15.708 = **32.070 m3**

3. Comparison original to proposed situation, rainwater towards the sea in year 2018:

Original situation = 228.300 m3
Proposed situation = 32.070 m3

Less water towards the sea = 196.230 m3 or 86% of the original volume of rainwater.

2. 4 Peak flow calculations periods with highest rainfall in 2017

Period 21-Feb-2017 + 22-Feb-2017:

21-Feb-2017 / 18.5 mm:

- Stor-01 max water depth = 5.62m / peak inflow = 1.48 m3/s
- Max water level = 47.62m (bottom = 42m) / wear is 49m = no overflow
- Stor-02 max water depth = 1.03m / peak inflow = 0.13 m3/s
- Max water level = 29.03m (bottom = 28m) / wear is 31m = no overflow
- Out-01 = 0.07 m3/s
- Out-02 = 0.08 m3/s
- Total volume out = 504 m3

22-Feb-2017 / 1.6 mm:

- Stor-01 max water depth = 5.92m / peak inflow = 0.13 m3/s
- Max water level = 47.92m (start = 46.62m) / wear is 49m = no overflow
- Stor-02 max water depth = 1.09m (start = 29.03m) / peak inflow = 0.01 m3/s
- Max water level = 29.09m / wear is 31m = no overflow
- Out-01 = 0.01 m3/s
- Out-02 = 0.01 m3/s
- Total volume out = 40 m3

Period 9-April-2017 + 10-April-2017:

9-April-2017 / 23.8 mm:

- Stor-01 max water depth = 6.56m / peak inflow = 1.90 m3/s
- Max water level = 48.56m (bottom = 42m) / wear is 49m = no overflow
- Stor-02 max water depth = 1.23m (bottom = 28m) / peak inflow = 0.16 m3/s
- Max water level = 29.23m / wear is 31m = no overflow
- Out-01 = 0.08 m3/s
- Out-02 = 0.10 m3/s
- Total volume out = 648 m3

10-April-2017 / 2.2 mm:

- Stor-01 max water depth = 6.92m / peak inflow = 0.18 m3/s
- Max water level = 48.92m (start = 48.56m) / wear is 49m = no overflow
- Stor-02 max water depth = 1.31m / peak inflow = 0.02 m3/s
- Max water level = 29.31m (start = 29.23m) / wear is 31m = no overflow
- Out-01 = 0.01 m3/s
- Out-02 = 0.01 m3/s
- Total volume out = 58 m3

Period 10-May-2017 + 11-May-2017:

10-May-2017 / 4.1 mm:

- Stor-01 max water depth = 4.85m / peak inflow = 0.33 m3/s
- Max water level = 46.85m (start = 45.92m) / wear is 49m = no overflow
- Stor-02 max water depth = 0.32m / peak inflow = 0.03 m3/s
- Max water level = 28.32m (start = 28m) / wear is 31m = no overflow
- Out-01 = 0.01 m3/s
- Out-02 = 0.02 m3/s
- Total volume out = 108 m3

11-May-2017 / 57.6 mm:

- Stor-01 max water depth = 7.63m / peak inflow = 4.60 m3/s
- Max water level = 49.63m (start = 46.85m) / wear is 49m = overflow = 4.60 m3/s
- Stor-02 max water depth = 3.67m / peak inflow = 5.00 m3/s
- Max water level = 31.67m (start = 28.32m) / wear is 31m = **overflow = 5.00 m3/s**
- Out-01 = 5.20 m3/s
- Out-02 = 0.24 m3/s
- Total volume out = 11.052 m3

Period 29-May-2017 + 30-May-2017:

29-May-2017 / 24.6 mm:

- Stor-01 max water depth = 7.36m / peak inflow = 1.96 m3/s
- Max water level = 49.36m (start (18d) = 47.20m) / wear is 49m = overflow = 1.96 m3/s
- Stor-02 max water depth = 3.38m / peak inflow = 2.13 m3/s
- Max water level = 31.38m (start (18d) = 29.20m) / wear is 31m = **overflow = 2.12 m3/s**
- Out-01 = 2.20 m3/s
- Out-02 = 0.10 m3/s
- Total volume out = 2.124 m3

30-May-2017 / 4.9 mm:

- Stor-01 max water depth = 7.12m / peak inflow = 0.39 m3/s
- Max water level = 49.12m (start = 49)/ wear is 49m = overflow = 0.39 m3/s
- Stor-02 max water depth = 3.13m (start = 31) / peak inflow = 0.43 m3/s
- Max water level = 31.13m / wear is 31m = **overflow = 0.43 m3/s**
- Out-01 = 0.44 m3/s
- Out-02 = 0.02 m3/s
- Total volume out = 1.224 m3

Period 19-Sept-2017 + 20-Sept-2017:

19-Sept-2017 / 4.5 mm:

- Stor-01 max water depth = 2.16m / peak inflow = 0.36 m3/s
- Max water level = 44.16m (start = 42m) / wear is 49m = no overflow
- Stor-02 max water depth = 0.35m / peak inflow = 0.03 m3/s
- Max water level = 28.35m (start = 28m) / wear is 31m = no overflow
- Out-01 = 0.02 m3/s
- Out-02 = 0.02 m3/s
- Total volume out = 119 m3

20-Sept-2017 / 24.3 mm:

- Stor-01 max water depth = 7.26m / peak inflow = 1.94 m3/s
- Max water level = 49.26m (start = 44.16m) / wear is 49m = overflow = 1.20 m3/s
- Stor-02 max water depth = 1.60m / peak inflow = 1.31 m3/s
- Max water level = 29.60m (start = 28.35m) / wear is 31m = no overflow
- Out-01 = 0.09 m3/s
- Out-02 = 0.10 m3/s
- Total volume out = 648 m3

Period 10-Oct-2017 + 11-Oct-2017 + 15-Oct-2017:

10-Oct-2017 / 38.2 mm:

- Stor-01 max water depth = 7.48m / peak inflow = 3.05 m3/s
- Max water level = 49.48m (start (20d) = 47.26m) / wear is 49m = overflow = 3.05 m3/s
- Stor-02 max water depth = 3.51m / peak inflow = 3.31 m3/s
- Max water level = 31.51m (start (20d) = 28m) / wear is 31m = **overflow = 3.31 m3/s**
- Out-01 = 3.45 m3/s
- Out-02 = 0.16 m3/s
- Total volume out = 5.688 m3

11-Oct-2017 / 14.7 mm:

- Stor-01 max water depth = 7.25m / peak inflow = 1.17 m3/s
- Max water level = 49.25m (start = 49)/ wear is 49m = overflow = 1.17 m3/s
- Stor-02 max water depth = 3.27m (start = 31) / peak inflow = 1.28 m3/s
- Max water level = 31.27m / wear is 31m = **overflow = 1.28 m3/s**
- Out-01 = 1.33 m3/s
- Out-02 = 0.06 m3/s
- Total volume out = 3.966 m3

15-Oct-2017 / 90.3 mm:

- Stor-01 max water depth = 7.85m / peak inflow = 7.21 m3/s
- Max water level = 49.85m (start 4d = 48.85)/ wear is 49m = overflow = 7.21 m3/s
- Stor-02 max water depth = 3.90m (start = 30.87) / peak inflow = 7.83 m3/s
- Max water level = 31.90m / wear is 31m = **overflow = 7.83 m3/s**
- Out-01 = 8.15 m3/s
- Out-02 = 0.37 m3/s
- Total volume out = 26.208 m3

2. 5 Other periods with less rainfall in 2017

The other periods in 2017 with less rainfall are assumed they would fill the two dams to a certain extent, with no overflow and consequently low peak flow on the harbor area and low peak flow towards the sea.

2. 6 Conclusions impact rainfall as was in 2017 and comparison to original

Overflow:
From above mentioned calculations with assumed rainfall as was in 2017 it is concluded that the dam system (southern dam) would have overflow on May 11th, May 29th, May 30th, October 10th , October 11th and October 15th, meaning a total of 6 times in this year.

Volumes of water towards the sea for a period of one year:

Calculation original situation rainfall in one year as in 2017, water towards the sea:

Rainfall x area x runoff coefficient = 1.1183 x 550.000 m2 x 0.62 = **381.238 m3**

Calculation new situation with detention ponds and rainfall as in 2017, water towards the sea:

1. highest daily rainfall periods

21 Feb	504 m3	19-Sept	119 m3
22 Feb	40 m3	20-Sept	648 m3
9 Apr	648 m3	10-Oct	5.688 m3
10 Apr	58 m3	11-Oct	3.996 m3
10 May	108 m3	15-Oct	26.208 m3
11 May	11.052 m3		
29 May	2.124 m3		
30 May	1.224 m3		

Total 13 days 52.417 m3

2. average daily rainfall periods

Total rainfall one year = 1118.3mm
Highest rainfall periods = 309.3 mm
Average daily rainfall outside higher rainfall periods = 809mm /352 days = 2.30 mm
Area runoff coefficient 0.62 = 37600 m2 (upstream below ponds)
Area runoff coefficient 0.96 = 4400 m2 (harbor area)

Rainfall 352 days: (0.0023 x 37600 x 0.67) + (0.0023 x 4400 x 0.96) = **67.66 m3/day**
67.66m3 x 352 = 23.816 m3

Total volume of water towards the sea with detention ponds = **76.233 m3**

3. Comparison original to proposed situation, rainwater towards the sea:

Original situation = 381.238 m3
Proposed situation = 76.233 m3

Less water towards the sea = 305.005 m3 or 80% of the original volume of rainwater.

Attachments: Rainfall info 2018 and 2017 Saba Airport, KNMI

Attachments:

- **Rainfall info 2018 Saba Airport, KNMI**
- **Rainfall info 2017 Saba Airport, KNMI**

daily rainfall 2018, KNMI data (mm)

year	month	day	RG24
2018	1	1	0
2018	1	2	0
2018	1	3	0
2018	1	4	0
2018	1	5	10
2018	1	6	5.4
2018	1	7	0.2
2018	1	8	5.4
2018	1	9	0
2018	1	10	0
2018	1	11	0
2018	1	12	1.7
2018	1	13	0.3
2018	1	14	0
2018	1	15	0
2018	1	16	0.8
2018	1	17	0
2018	1	18	0.5
2018	1	19	0.5
2018	1	20	0
2018	1	21	0
2018	1	22	0.1
2018	1	23	0
2018	1	24	1.9
2018	1	25	0.6
2018	1	26	0
2018	1	27	3.4
2018	1	28	0.4
2018	1	29	7.8
2018	1	30	0
2018	1	31	0
2018	2	1	0.1
2018	2	2	0.3
2018	2	3	0
2018	2	4	1
2018	2	5	3.8
2018	2	6	0.8
2018	2	7	0.3
2018	2	8	0
2018	2	9	2.1
2018	2	10	2.3
2018	2	11	3.2
2018	2	12	0.8
2018	2	13	4.6
2018	2	14	1.3
2018	2	15	0.2
2018	2	16	7.3
2018	2	17	0
2018	2	18	1
2018	2	19	0
2018	2	20	0
2018	2	21	1.6
2018	2	22	1.1
2018	2	23	2
2018	2	24	0.1
2018	2	25	1.3
2018	2	26	0.3
2018	2	27	0
2018	2	28	0
2018	3	1	0
2018	3	2	0
2018	3	3	0
2018	3	4	0.4
2018	3	5	0.5
2018	3	6	0
2018	3	7	0
2018	3	8	0
2018	3	9	0
2018	3	10	0
2018	3	11	0
2018	3	12	0
2018	3	13	0
2018	3	14	0
2018	3	15	0
2018	3	16	0
2018	3	17	0
2018	3	18	0
2018	3	19	0
2018	3	20	0
2018	3	21	0.3
2018	3	22	5
2018	3	23	0.1
2018	3	24	0.1
2018	3	25	0
2018	3	26	0.9
2018	3	27	0
2018	3	28	0
2018	3	29	0
2018	3	30	0
2018	3	31	0
2018	4	1	0
2018	4	2	0
2018	4	3	0

2018 highest daily rainfall periods (mm)

5-Jan	10	27-May	32.9	29-Aug	30.8	14-Sep	51
6-Jan	5.4	28-May	0.1	30-Aug	13.5	15-Sep	1.4

2018 monthly rainfall (mm)

jan	feb	mrt	april	mei	juni	juli	aug	sep	okt	nov	dec	year
39	35.5	7.3	41.8	51.3	39	41	71.4	135.3	76.4	76.2	55.3	669.5

average 1971-2000 monthly rainfall (mm)

jan	feb	mrt	april	mei	juni	juli	aug	sep	okt	nov	dec	year
36.8	75.3	35.4	28.1	95.9	44.4	60.8	77	60.5	35.5	134.5	76.5	760.7

2018	4	4	0.1
2018	4	5	0
2018	4	6	0
2018	4	7	0.1
2018	4	8	0
2018	4	9	1.6
2018	4	10	2.6
2018	4	11	4.3
2018	4	12	1.5
2018	4	13	2.2
2018	4	14	3.1
2018	4	15	0.1
2018	4	16	0
2018	4	17	0
2018	4	18	4.6
2018	4	19	0.2
2018	4	20	6.3
2018	4	21	0
2018	4	22	1.6
2018	4	23	11.9
2018	4	24	0
2018	4	25	0.2
2018	4	26	1.1
2018	4	27	0
2018	4	28	0
2018	4	29	0
2018	4	30	0.3
2018	5	1	0
2018	5	2	0
2018	5	3	1.8
2018	5	4	0.2
2018	5	5	0.1
2018	5	6	0.2
2018	5	7	0
2018	5	8	0
2018	5	9	2.9
2018	5	10	0
2018	5	11	1.2
2018	5	12	0
2018	5	13	0
2018	5	14	0
2018	5	15	0
2018	5	16	0.2
2018	5	17	4.3
2018	5	18	2.1
2018	5	19	0
2018	5	20	2.5
2018	5	21	0.2
2018	5	22	0.2
2018	5	23	0
2018	5	24	0
2018	5	25	0
2018	5	26	1
2018	5	27	32.9
2018	5	28	0.1
2018	5	29	1.3
2018	5	30	0.1
2018	5	31	0
2018	6	1	0
2018	6	2	0
2018	6	3	0
2018	6	4	0
2018	6	5	0
2018	6	6	0.3
2018	6	7	0.2
2018	6	8	0
2018	6	9	0
2018	6	10	9.8
2018	6	11	3.5
2018	6	12	0.7
2018	6	13	0
2018	6	14	0
2018	6	15	0
2018	6	16	0
2018	6	17	0
2018	6	18	0
2018	6	19	0.1
2018	6	20	0
2018	6	21	0
2018	6	22	0.9
2018	6	23	20
2018	6	24	0
2018	6	25	0.2
2018	6	26	0.6
2018	6	27	2.4
2018	6	28	0.1
2018	6	29	0.2
2018	6	30	0
2018	7	1	0
2018	7	2	0
2018	7	3	0.1
2018	7	4	0
2018	7	5	0
2018	7	6	0.1
2018	7	7	0

2018	7	8	0.5
2018	7	9	12
2018	7	10	0
2018	7	11	0
2018	7	12	0
2018	7	13	0
2018	7	14	0.2
2018	7	15	2.7
2018	7	16	2.3
2018	7	17	0.5
2018	7	18	0
2018	7	19	2.7
2018	7	20	0.4
2018	7	21	0.2
2018	7	22	0.7
2018	7	23	0
2018	7	24	6.6
2018	7	25	10.9
2018	7	26	0.1
2018	7	27	0
2018	7	28	0.3
2018	7	29	0
2018	7	30	0.7
2018	7	31	0
2018	8	1	0.2
2018	8	2	0
2018	8	3	0.5
2018	8	4	5.2
2018	8	5	0.3
2018	8	6	0.3
2018	8	7	0
2018	8	8	0
2018	8	9	0
2018	8	10	0
2018	8	11	1.4
2018	8	12	0
2018	8	13	0
2018	8	14	0.5
2018	8	15	2
2018	8	16	4.8
2018	8	17	0.6
2018	8	18	0
2018	8	19	0
2018	8	20	0.6
2018	8	21	4.8
2018	8	22	1.7
2018	8	23	0
2018	8	24	0.7
2018	8	25	0
2018	8	26	2.9
2018	8	27	0.5
2018	8	28	0.1
2018	8	29	30.8
2018	8	30	13.5
2018	8	31	0
2018	9	1	0.3
2018	9	2	7.8
2018	9	3	9.6
2018	9	4	1
2018	9	5	0
2018	9	6	0
2018	9	7	0
2018	9	8	0
2018	9	9	0
2018	9	10	1.4
2018	9	11	0
2018	9	12	17.9
2018	9	13	2.4
2018	9	14	51
2018	9	15	1.4
2018	9	16	0
2018	9	17	1.3
2018	9	18	1.1
2018	9	19	0.7
2018	9	20	0
2018	9	21	5.4
2018	9	22	5.2
2018	9	23	0
2018	9	24	0.9
2018	9	25	0.3
2018	9	26	27
2018	9	27	0.1
2018	9	28	0.1
2018	9	29	0.4
2018	9	30	0
2018	10	1	3.1
2018	10	2	0
2018	10	3	0
2018	10	4	0
2018	10	5	2
2018	10	6	2.3
2018	10	7	0
2018	10	8	0
2018	10	9	0
2018	10	10	7.7

2018	10	11	2.4
2018	10	12	2.3
2018	10	13	25
2018	10	14	5.5
2018	10	15	11.6
2018	10	16	0.2
2018	10	17	9.9
2018	10	18	0
2018	10	19	0.1
2018	10	20	0
2018	10	21	0.4
2018	10	22	2.6
2018	10	23	0.3
2018	10	24	0
2018	10	25	0
2018	10	26	0
2018	10	27	0
2018	10	28	0
2018	10	29	0
2018	10	30	1
2018	10	31	0
2018	11	1	0
2018	11	2	10.5
2018	11	3	5.8
2018	11	4	0
2018	11	5	9.6
2018	11	6	0
2018	11	7	2.1
2018	11	8	0.1
2018	11	9	21
2018	11	10	1.8
2018	11	11	0
2018	11	12	2.1
2018	11	13	10.7
2018	11	14	3.5
2018	11	15	2.7
2018	11	16	4.6
2018	11	17	0
2018	11	18	0
2018	11	19	0
2018	11	20	0.7
2018	11	21	0
2018	11	22	0.4
2018	11	23	0
2018	11	24	0
2018	11	25	0
2018	11	26	0
2018	11	27	0
2018	11	28	0
2018	11	29	0
2018	11	30	0.6
2018	12	1	6.9
2018	12	2	0
2018	12	3	0
2018	12	4	0
2018	12	5	6.6
2018	12	6	0.3
2018	12	7	1.9
2018	12	8	5.9
2018	12	9	0.1
2018	12	10	0
2018	12	11	0
2018	12	12	0
2018	12	13	0.2
2018	12	14	0.2
2018	12	15	1.3
2018	12	16	1.2
2018	12	17	0.1
2018	12	18	0
2018	12	19	0
2018	12	20	0
2018	12	21	0
2018	12	22	5.2
2018	12	23	0
2018	12	24	0.2
2018	12	25	0
2018	12	26	5
2018	12	27	2.2
2018	12	28	6.1
2018	12	29	10.4
2018	12	30	0
2018	12	31	1.5

daily rainfall 2017, KNMI data (mm)

year	month	day	RG24
2017	1	1	0.0
2017	1	2	0.2
2017	1	3	3.0
2017	1	4	0.0
2017	1	5	0.3
2017	1	6	0.0
2017	1	7	2.9
2017	1	8	0.0
2017	1	9	0.1
2017	1	10	7.1
2017	1	11	3.0
2017	1	12	3.2
2017	1	13	2.4
2017	1	14	2.5
2017	1	15	0.8
2017	1	16	1.3
2017	1	17	0.1
2017	1	18	5.5
2017	1	19	0.0
2017	1	20	0.1
2017	1	21	0.0
2017	1	22	0.0
2017	1	23	0.0
2017	1	24	1.2
2017	1	25	1.8
2017	1	26	0.0
2017	1	27	2.0
2017	1	28	0.1
2017	1	29	0.0
2017	1	30	2.4
2017	1	31	3.9
2017	2	1	0.2
2017	2	2	0.0
2017	2	3	0.1
2017	2	4	0.9
2017	2	5	0.0
2017	2	6	0.3
2017	2	7	0.1
2017	2	8	0.0
2017	2	9	0.0
2017	2	10	0.6
2017	2	11	2.7
2017	2	12	0.0
2017	2	13	0.0
2017	2	14	6.9
2017	2	15	0.0
2017	2	16	0.0
2017	2	17	0.0
2017	2	18	0.0
2017	2	19	0.0
2017	2	20	0.0
2017	2	21	18.5
2017	2	22	1.6
2017	2	23	0.7
2017	2	24	0.1
2017	2	25	0.5
2017	2	26	0.0
2017	2	27	2.1
2017	2	28	1.0
2017	3	1	0.2
2017	3	2	0.3
2017	3	3	0.9
2017	3	4	1.2
2017	3	5	0.0
2017	3	6	0.5
2017	3	7	14.9
2017	3	8	0.0
2017	3	9	0.9
2017	3	10	0.0
2017	3	11	0.0
2017	3	12	0.0
2017	3	13	0.0
2017	3	14	0.6
2017	3	15	1.0
2017	3	16	0.0
2017	3	17	6.0
2017	3	18	0.145
2017	3	19	7.0
2017	3	20	0.0
2017	3	21	0.0
2017	3	22	3.7
2017	3	23	0.0
2017	3	24	0.0
2017	3	25	0.1
2017	3	26	0.0
2017	3	27	0.0
2017	3	28	0.0
2017	3	29	0.0
2017	3	30	0.0
2017	3	31	0.0
2017	4	1	0.0
2017	4	2	0.0

2017 highest daily rainfall periods (mm)

21-Feb	22-Feb	9-Apr	10-Apr	10-May	11-May	29-May	30-May	19-Sep	20-Sep	10-Oct	11-Oct	15-Oct
18.5	1.6	23.8	2.2	4.1	57.6	24.6	4.9	4.5	24.3	38.2	14.7	90.3

= missing data, added with assumed rainfall

2017 monthly rainfall (mm)

jan	feb	mrt	april	mei	juni	juli	aug	sep	okt	nov	dec	year
43.8	36.4	37.5	64.9	111.6	53.8	111.2	69.7	102.1	297.6	21.1	168.6	1118.3

average 1971-2000 monthly rainfall (mm)

jan	feb	mrt	april	mei	juni	juli	aug	sep	okt	nov	dec	year
36.8	75.3	35.4	28.1	95.9	44.4	60.8	77	60.5	35.5	134.5	76.5	760.7

total year 2017	13 highest rainfall days	365 - 13 days	average for 352 days
1118.3	309.3	809.0	2.30

2017	4	3	0.0
2017	4	4	0.0
2017	4	5	0.0
2017	4	6	0.0
2017	4	7	0.0
2017	4	8	0.0
2017	4	9	23.8
2017	4	10	2.2
2017	4	11	0.0
2017	4	12	0.0
2017	4	13	0.0
2017	4	14	5.5
2017	4	15	1.1
2017	4	16	0.0
2017	4	17	13.4
2017	4	18	0.0
2017	4	19	0.0
2017	4	20	7.4
2017	4	21	0.0
2017	4	22	0.0
2017	4	23	0.0
2017	4	24	0.7
2017	4	25	5.0
2017	4	26	0.0
2017	4	27	1.5
2017	4	28	2.7
2017	4	29	1.4
2017	4	30	0.0
2017	5	1	5.0
2017	5	2	0.0
2017	5	3	0.0
2017	5	4	2.8
2017	5	5	0.0
2017	5	6	0.0
2017	5	7	0.0
2017	5	8	0.0
2017	5	9	0.0
2017	5	10	4.1
2017	5	11	57.6
2017	5	12	0.0
2017	5	13	0.0
2017	5	14	0.0
2017	5	15	0.0
2017	5	16	0.0
2017	5	17	0.0
2017	5	18	0.0
2017	5	19	0.0
2017	5	20	0.0
2017	5	21	0.0
2017	5	22	0.0
2017	5	23	0.0
2017	5	24	0.0
2017	5	25	0.0
2017	5	26	1.6
2017	5	27	9.1
2017	5	28	1.2
2017	5	29	24.6
2017	5	30	4.9
2017	5	31	0.6
2017	6	1	0.3
2017	6	2	4.0
2017	6	3	0.2
2017	6	4	6.4
2017	6	5	0.0
2017	6	6	0.2
2017	6	7	0.1
2017	6	8	15.7
2017	6	9	5.7
2017	6	10	0.0
2017	6	11	5.3
2017	6	12	0.0
2017	6	13	0.0
2017	6	14	0.0
2017	6	15	0.1
2017	6	16	0.0
2017	6	17	1.3
2017	6	18	0.4
2017	6	19	0.3
2017	6	20	0.0
2017	6	21	3.3
2017	6	22	2.0
2017	6	23	4.8
2017	6	24	1.5
2017	6	25	1.4
2017	6	26	0.2
2017	6	27	0.1
2017	6	28	0.0
2017	6	29	0.8
2017	6	30	0.0
2017	7	1	5.0
2017	7	2	0.0
2017	7	3	10.0
2017	7	4	0.0
2017	7	5	5.0

2017	7	6	0.0
2017	7	7	10.0
2017	7	8	0.0
2017	7	9	5.0
2017	7	10	0.0
2017	7	11	10.0
2017	7	12	0.0
2017	7	13	5.0
2017	7	14	0.0
2017	7	15	10.0
2017	7	16	0.0
2017	7	17	5.0
2017	7	18	0.0
2017	7	19	10.0
2017	7	20	0.0
2017	7	21	5.0
2017	7	22	0.3
2017	7	23	10.0
2017	7	24	0.0
2017	7	25	5.0
2017	7	26	0.0
2017	7	27	10.0
2017	7	28	0.0
2017	7	29	5.0
2017	7	30	0.0
2017	7	31	0.9
2017	8	1	0.0
2017	8	2	12.1
2017	8	3	0.7
2017	8	4	0.0
2017	8	5	0.0
2017	8	6	0.1
2017	8	7	0.1
2017	8	8	0.0
2017	8	9	2.3
2017	8	10	0.0
2017	8	11	2.0
2017	8	12	0.0
2017	8	13	0.0
2017	8	14	11.9
2017	8	15	0.0
2017	8	16	23.5
2017	8	17	5.9
2017	8	18	0.7
2017	8	19	1.7
2017	8	20	1.4
2017	8	21	0.0
2017	8	22	0.0
2017	8	23	0.0
2017	8	24	1.1
2017	8	25	0.1
2017	8	26	0.8
2017	8	27	0.6
2017	8	28	4.4
2017	8	29	0.2
2017	8	30	0.0
2017	8	31	0.0
2017	9	1	3.6
2017	9	2	0.4
2017	9	3	0.4
2017	9	4	0.3
2017	9	5	2.3
2017	9	6	0.0
2017	9	7	0.0
2017	9	8	0.0
2017	9	9	9.9
2017	9	10	1.9
2017	9	11	0.4
2017	9	12	0.0
2017	9	13	0.0
2017	9	14	0.6
2017	9	15	18.4
2017	9	16	3.0
2017	9	17	0.2
2017	9	18	0.1
2017	9	19	4.5
2017	9	20	24.3
2017	9	21	8.1
2017	9	22	0.0
2017	9	23	0.0
2017	9	24	0.0
2017	9	25	0.3
2017	9	26	0.2
2017	9	27	0.9
2017	9	28	8.1
2017	9	29	0.0
2017	9	30	14.4
2017	10	1	0.0
2017	10	2	0.4
2017	10	3	15.0
2017	10	4	0.0
2017	10	5	10.0
2017	10	6	1.5
2017	10	7	1.6

2017	10	8	15.0
2017	10	9	0.0
2017	10	10	38.2
2017	10	11	14.7
2017	10	12	0.0
2017	10	13	3.0
2017	10	14	0.0
2017	10	15	90.3
2017	10	16	0.0
2017	10	17	15.0
2017	10	18	0.0
2017	10	19	10.0
2017	10	20	0.0
2017	10	21	15.0
2017	10	22	0.0
2017	10	23	10.0
2017	10	24	0.0
2017	10	25	15.0
2017	10	26	0.0
2017	10	27	17.9
2017	10	28	0.0
2017	10	29	15.0
2017	10	30	0.0
2017	10	31	10.0
2017	11	1	0.0
2017	11	2	0.0
2017	11	3	0.6
2017	11	4	2.4
2017	11	5	1.3
2017	11	6	2.5
2017	11	7	0.0
2017	11	8	4.2
2017	11	9	0.0
2017	11	10	1.7
2017	11	11	0.1
2017	11	12	0.0
2017	11	13	0.0
2017	11	14	0.1
2017	11	15	0.0
2017	11	16	0.7
2017	11	17	4.9
2017	11	18	1.3
2017	11	19	0.0
2017	11	20	0.0
2017	11	21	0.0
2017	11	22	0.1
2017	11	23	0.4
2017	11	24	0.1
2017	11	25	0.5
2017	11	26	0.0
2017	11	27	0.0
2017	11	28	0.0
2017	11	29	0.2
2017	11	30	0.0
2017	12	1	15.0
2017	12	2	0.7
2017	12	3	5.0
2017	12	4	3.1
2017	12	5	0.0
2017	12	6	0.2
2017	12	7	6.9
2017	12	8	15.0
2017	12	9	0.1
2017	12	10	3.9
2017	12	11	6.0
2017	12	12	10.0
2017	12	13	2.0
2017	12	14	10.0
2017	12	15	0.1
2017	12	16	5.0
2017	12	17	3.5
2017	12	18	15.0
2017	12	19	0.4
2017	12	20	0.4
2017	12	21	0.2
2017	12	22	16
2017	12	23	0.0
2017	12	24	5.0
2017	12	25	0.0
2017	12	26	15.0
2017	12	27	0.0
2017	12	28	15.0
2017	12	29	0.0
2017	12	30	15.0
2017	12	31	0.0

Annex 11: Relevant information on use of Delft3D and modelling assumptions

Annex 11 Calculations SCC and deposition, assumptions

Dredging and harbor construction activities cause sediments to disperse to nearby coral reefs. This note describes the assumptions used for setting up a hydrodynamic model to determine suspended solids concentrations (SSC) and deposition of these sediments.

The far field dispersion of brine in the sea was modelled using the program Delft3D (version: 2020.05). The software programs DelftDashboard and dxf2xyz were used for processing the bathymetry.

The Delft3D model is comprised of two parts. The (1) FlowFM model which is used to model the ocean currents and (2) the Water Quality model which is used to model the dispersion of sediment using ocean currents from the FlowFM model.
Two dimensional modelling was used (concentrations of SSC averaged over the water column).

The following paragraphs describe the setup of the model:
1. Modelling area
2. Bathymetry and bottom roughness
3. Boundary conditions
4. Modelling period & time steps
5. Observation points
6. Calculation of settling velocity
7. Calculation of sediment loads
8. Sensitivity analysis

1. Modelling area

The modelling area consists of 625 km^2 (25x25km) with the island of Saba situated in the centre of the modelling area. A grid was projected on the modelling area including several refinements at the area to study. The finer grid consists of cells of 18 by 18 metres. A figure of the grid is shown in figure 1.

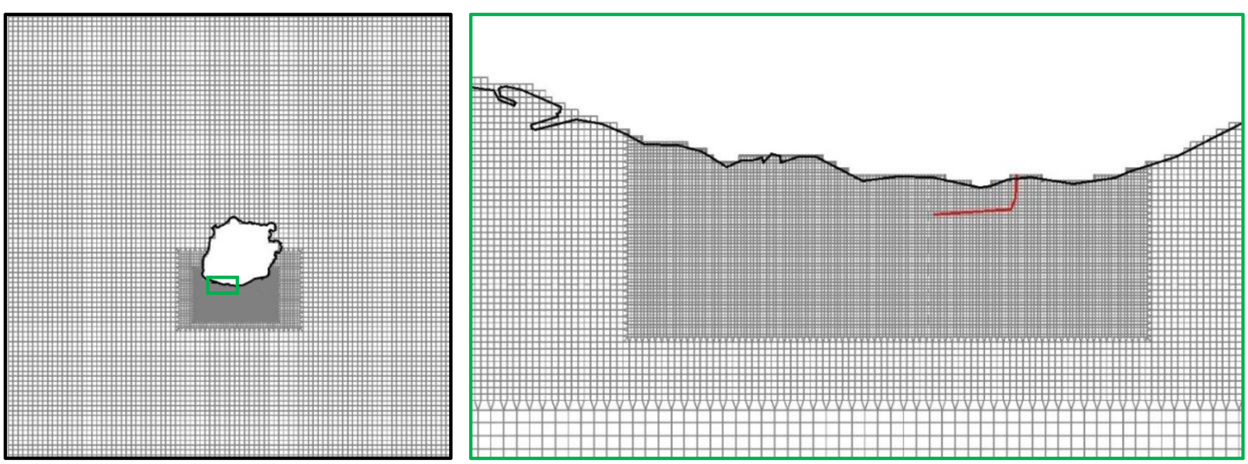


Figure 1: Grid used in model (left) with magnification of grid (right) at harbour area.

2. Bathymetry and bottom roughness

For the bathymetry depth contours surrounding Saba were introduced. As a simplification of the model, all depths greater than 100 metres were set to a fixed value of 100 metres. This improves the water balance over the boundaries, and has only minor ramifications for the final results (pers. comm. Deltares).

For bottom roughness, used by Delft3D to determine the bottom friction, the uniform friction type 'Manning' was selected with a uniform friction coefficient of 0.023 (comparable to roughness of firm gravel). An illustration of the bathymetry is shown in figure 2.

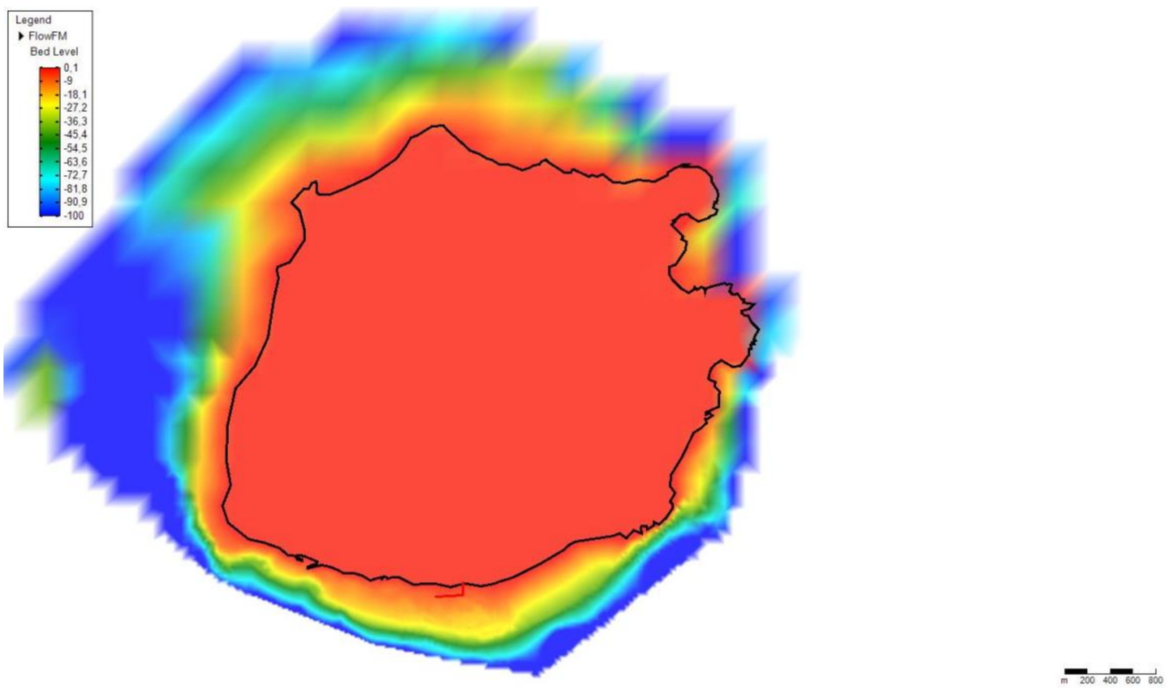


Figure 2: Bathymetry around Saba used for the Delft3D model.

3. Boundary conditions

No data are available on current velocities near the coast (pers. comm. Harbor Master). Current velocities in the northeastern Caribbean (at open sea) are significantly lower than in the southern Caribbean (Gyory et al. The Caribbean Current[1]). Near the coast, local factors such as wind and waves also play an important role. Current velocities near Curaçao at open sea average 34 cm/s (surface current, 2 km northeast of Curaçao, HYCOM model) and currents close to the shore (near Annabaai[2], measured by CPA[3]) average 17 cm/s. Although many local factors are unknown we assume that average current velocity in Saba is significantly lower, in the range of 6 cm/s (very low) to 16 cm/s (relatively

[1] Joanna Gyory, Arthur J. Mariano, Edward H. Ryan. "The Caribbean Current." Ocean Surface Currents. https://oceancurrents.rsmas.miami.edu/caribbean/caribbean.html

[2] Currents not related to tides

[3] Buoy anchored at 13 meters, measurement depth 3 meters

high). A scenario with average current of 11 cm/s was selected for modelling for the EIA, the scenario's with average current of 6 cm/s and 17 cm/s (+/- 50%) were used for a sensitivity analysis (paragraph 8).

Ocean current advection was selected as the forcing for the model (advection at surface layer at the nearest HYCOM modelling point, 2 km east of Saba). The vectors u (east-west) and v (north-south) were used to calculate a discharge over the A and B boundary respectively by multiplying by 2.5×10^6 (25 km boundary 100m deep) and a fixed factor (identical for both boundaries), in order to match the requirement of average current of 11 cm/s. On the west and north side of the modelling area a fixed water level boundary was defined.
It was assumed that tidal waves, salinity, temperature and wind forcing were less significant and these types of forcing were excluded from the model.
The modelling period was 6 weeks (mid February-March, 2018).

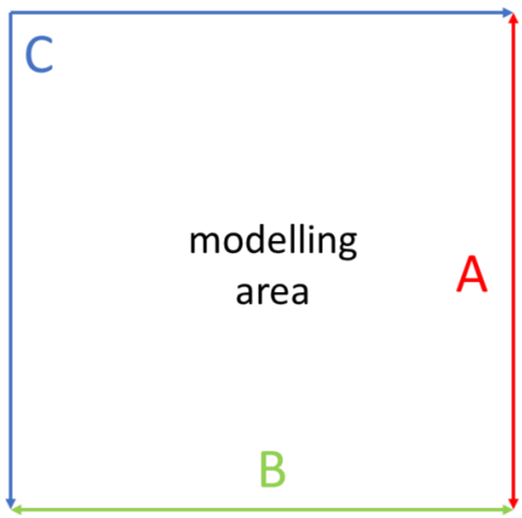


Figure 3 Illustration of orientation boundaries to modelling area

Figure 4 shows current velocities modelled near the Black Rock harbour area during one month (March 2018). Note that the current reverses several times during that month.

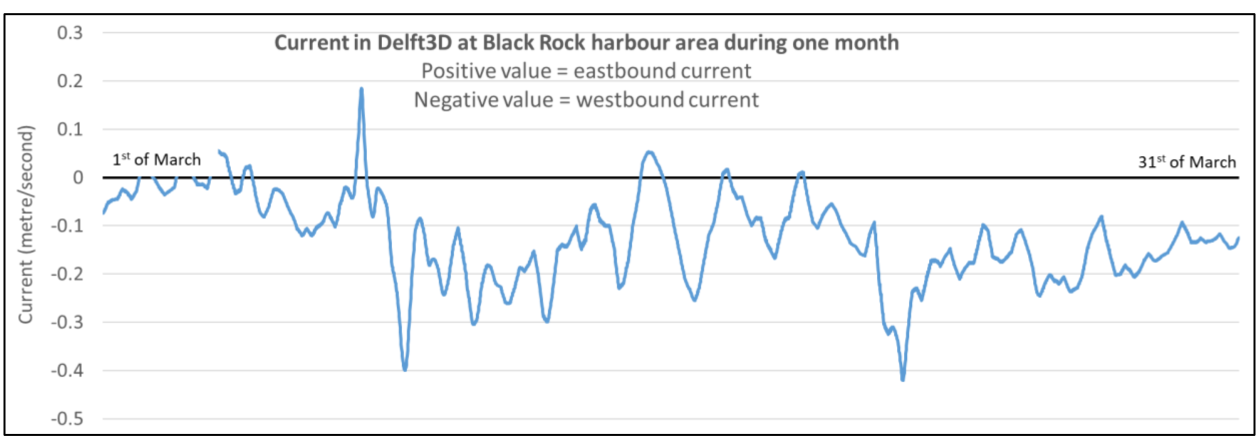


Figure 4 Modelled current velocity during March 2018 at Black Rock Harbour (average 11 cm/s; positive values indicate current reversals).

4. Modelling period & time steps

The modelling period was set for the month of March 2018 with an output time step interval of fifteen minutes. The last eight days of February were included in the flow-model to allow for stabilisation of the model. The period of March was selected because the HYCOM data showed this month to have several reversals of the sea current.

5. Observation points

In the water quality model several observation points were introduced to calculate total suspended solids concentrations (SSC) and the deposition and at a specific location over time. These observation points are located at small coral reefs (patch reefs) near the proposed harbor.

Table 1: Observation points in Delft3D model.

Location	Coordinates			
	Pseudo mercator (EPSG:3857)		UTM zone 20N (EPSG:3262)	
	X	Y	X	Y
Patchreef 1	-7040498,21	1992328,68	473915,18	1947414,16
Patchreef 2	-7039968,29	1992339,10	474430,23	1947423,38
Patchreef 3	-7039751,83	1992274,21	474626,45	1947361,65
Patchreef 4	-7039689,99	1992371,54	474685,50	1947453,77
Greer Gut / GQ Shallow	-7040039,41	1992162,00	474352,23	1947255,71

6. Calculation settling velocity (particles)

The sedimentation settling speed was calculated for three particle fractions (63-20 µm, 20-6 µm and <6 µm) according to the Stokes-equation (formula 2). For each particle fraction a 'representative' particle diameter (D_{rep}) was first calculated according to formula 1 wherin 'D' is the particle diameter in micrometres.

$$D_{rep} = \sqrt{\frac{1}{2}\frac{D_{max}^4 - D_{min}^4}{D_{max}^2 - D_{min}^2}}$$ **Formula 1**

For example, a particle fraction of 63 to 20 µm results in a representative diameter of 46,7 µm according to formula 1.

$$v = \frac{2}{9}\frac{(\rho_p - \rho_f)}{\mu} g R^2$$ **Formula 2**

v	settling velocity (m/s)
µ	dynamic viscosity (kg/(m*s))
g	gravitational strength (m/s^2)
R	radius particle diameter (m)
ρ_p	mass density of the particles (kg/m^3)
ρ_f	mass density of the fluid (kg/m^3)

Table 2: Particle classes, representative diameters and settling speed

Particle fraction (µm)	Representative diameter (µm)	Settling speed (m/sec)	Settling speed (m/day)
150-60	115,0	0,0136668	1180,8
60-20	46,7	0,0022538	194,7
20-6	14,8	0,0002264	19,6
6-0	4,2	0,000009	0,804

7. Calculation of sediment loads

The sediment loads which are discharged into the sea were calculated for the (1) for the construction phase of the pier and (2) dredging operations. The sediment load during both dredging and construction was calculated according to formula 3.

$$Source\ term\ (\frac{kg}{sec}) = \frac{WP * dry\ density * 1000 * f_{<63um} * drip}{3600 * operating\ hours\ per\ week}$$ **Formula 3**

WP	weekly production (m³)
Dry density	kg/m³
$f_{< 63\ \mu m}$	fraction fines < 63 µm
drip	percentage of dredging material spilled into the sea

Table 3 and 4 present relevant input data for the hydraulic modelling.

Table 3 Relevant model input for construction (phases 2.1 and 2.5).

	Unit	Amount
Volume of core material for breakwater per phase	m3	3,500
Volume of backfill material (phase 2.5)	m3	2,000
Dry density	kg/l	1.5
Particle density	kg/l	2.75
Porosity		0.45
Fraction of fines <63µm (Annex 4)		0.33
Fraction <20µm (Annex 4)		0.09
Fraction < 6µm (Annex 4)		0.02
Fraction < 2µm (Annex 4)		0.001
Operational hours per week (12 hrs per day)	hr	84
Production rate (avg)	m3/hr	16
Source term factor for placement in sea[4]		0.05
Source term fines <63 µm	kg/sec	0.11
Duration of phase 2.1 and 2.5 (each)	weeks	2.6

The source term of 0.11 kg/s is entered in the hydraulic model (D-Flow FM/Water Quality) as a constant value. In reality the source term may vary, both in a spatial and a temporal sense. Spatial variability is limited since construction progresses slowly from day to day. Temporal variability may occur when differences in construction material (aggregates) are to be expected and when tipping of core material is

[4] Fraction of total fines brought into suspension by method used. Factor is the highest factor, corresponding with placement in open sea, with mechanically dredged material (as opposed to hydraulically dredged). Source: Dredging for sustainable infrastructure (2018)

intermittent. In the model used, we assume that this is not the case, i.e. uniform aggregates which are continuously distributed by a hydraulic excavator.

Table 4: Relevant model input for dredging of east and west part of harbour (phase 1 and 2)

	Unit	Phase 1	Phase 2
Volume of dredged material	m3	20,000	10,000
Dry density	kg/l	1.33	1.33
Particle density	kg/l	2.75	2.75
Porosity		0.45	0.45
Fraction of fines <63µm (Annex 4)		0.33	0.13
Fraction <20µm (Annex 4)		0.09	0.04
Fraction < 6µm (Annex 4)		0.02	0.008
Fraction < 2µm (Annex 4)		0.001	0.0004
Operational hours per week (12 hrs per day)	hr	84	84
Production rate (avg)	m3/hr	40	40
Source term factor for dredging[5]		0.10	0.10
Source term fines <63µm phase(*)	kg/sec	0.55	0.22
Duration of phase 2.1 and 2.5 (each)	weeks	8	4

The source term of 0.55 and 0.22 kg/s are entered in the hydraulic models (D-Flow FM and Water Quality) as constant values. In reality these source terms may vary, both in a spatial and a temporal sense. Spatial variability is limited since dredging progresses slowly from day to day. The daily spatial variation is not more than 15 meters in all directions (1 cell within modelling mesh). Temporal variability may occur when differences in fines concentration exist in the seafloor. In the model calculations we assume that this is not the case within the course of one day of working.

Table 5. gives an overview of the calculated sediment loads used for each scenario.

Table 5: Sediment emission used in Delft3D model.

	Sediment emission (kg/sec)			
Project phase	63-20 µm	20-6 µm	6-0 µm	Sum
Construction phase 1 Placement	0,080	0,023	0,0066	0,11
Construction phase 5 Placement	0,125	0,037	0,0104	0,17
Dredging phase 1 (in harbour)	0,400	0.117	0,033	0,55
Dredging phase 2 (west part and approach channel)	0,163	0,048	0,014	0,23

8. Sensitivity analysis

The sensitivity analysis has been carried out for patch reef 1, during construction in phase 2.1 and dredging in phase 2, with velocities deviating 50 % (+/-) from the average of 11 cm/s per second.
The average currents of 6 cm/s and 16 cm/s were established in the model by changing the average discharge over boundaries A and B proportionally.

The resulting current velocities are included in figure 5.

[5] Fraction of total fines brought into suspension by method used. Factor selected is the highest factor, corresponding with dredging by means of backhoe dredger (BHD). Source: Laboyrie et al, 2018

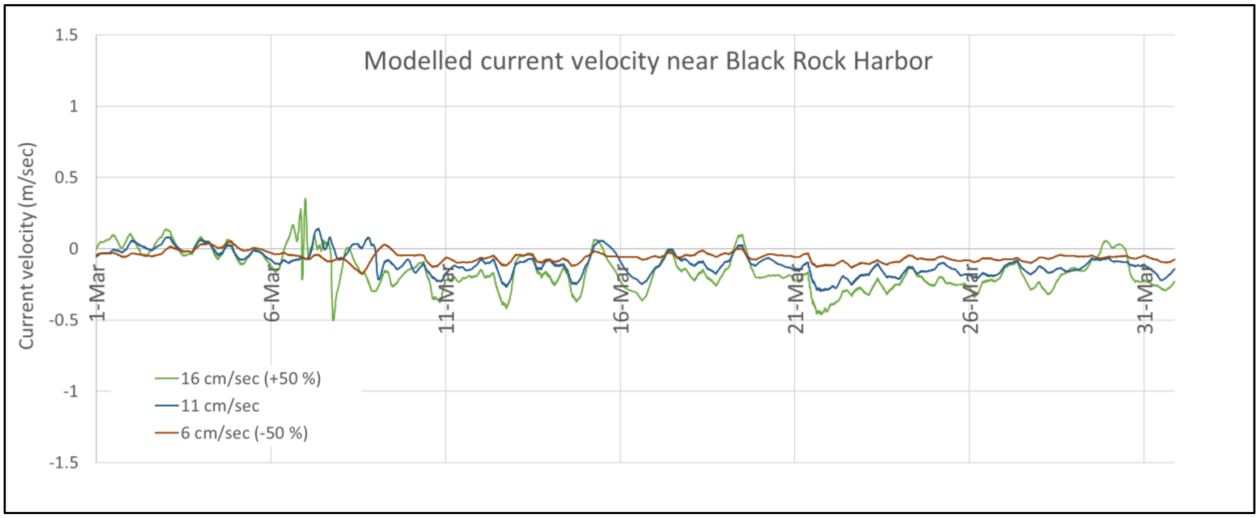


Figure 5: Current velocities sensitivity analysis

The analysis points out that suspended solids concentration (SSC) and deposition increase by a factor of maximally 30% (deposition) to 48% (average SSC) in the low current scenario, as compared to the 11 cm/s scenario (see tables 7-10).
Peak concentrations do not exceed the 1 mg/l at reef 1 and therefore the percentage of time in which 1, 2 or 5 mg/l is exceeded is zero in all cases.

Construction

Table 7: Sensitivity analysis of current velocity on average suspended solids concentration (SSC). Construction phase 2.1, Patch reef 1.

Fraction	Average concentration (g/m³)		
	6 cm/sec	11 cm/sec	16 cm/sec
IM1	0.00 (-27 %)	0,01	0.01 (-16 %)
IM2	0.03 (+56 %)	0,02	0.01 (-67 %)
IM3	0.01 (+73 %)	0,01	0.01 (+60 %)
Total	0.04 (+43 %)	0,03	0.02 (-25 %)

Table 8: Sensitivity analysis of current velocity on sediment deposition Construction phase 2.1, Patch reef 1.

Fraction	Deposition (mg/cm2/day)		
	6 cm/sec	11 cm/sec	16 cm/sec
IM1	0.05 (-15 %)	0,06	0.05 (-27 %)
IM2	0.04 (+80 %)	0,02	0.01 (-36 %)
IM3	0.00 (+92 %)	0,00	0.00 (-36 %)
Total	0.09 (+9 %)	0,08	0.06 (-29 %)

Dredging

Table 9: Sensitivity analysis of current velocity on average suspended solids concentration (SSC). Dredging phase 2, Patch reef 1.

Fraction	Average concentration (g/m^3)		
	6 cm/sec	11 cm/sec	16 cm/sec
IM1	0.03 (+9 %)	0,02	0.02 (-13 %)
IM2	0.07 (+62 %)	0,04	0.03 (-22 %)
IM3	0.03 (+68 %)	0,02	0.01 (-23 %)
Total	0.13 (+48 %)	0,08	0.07 (-20 %)

Table 10: Sensitivity analysis of current velocity on sediment deposition Dredging phase 2, Patch reef 1.

Fraction	Deposition (mg/cm^2/day)		
	6 cm/sec	11 cm/sec	16 cm/sec
IM1	0.30 (+20 %)	0,25	0.20 (-21 %)
IM2	0.09 (+72 %)	0,05	0.04 (-32 %)
IM3	0.00 (+75 %)	0,00	0.00 (-35 %)
Total	0.39 (+30 %)	0,30	0.23 (-23 %)

Annex 12: Erosion control measures for steep slopes

Erosion Control Toolbox: Wire Mesh Confinement System

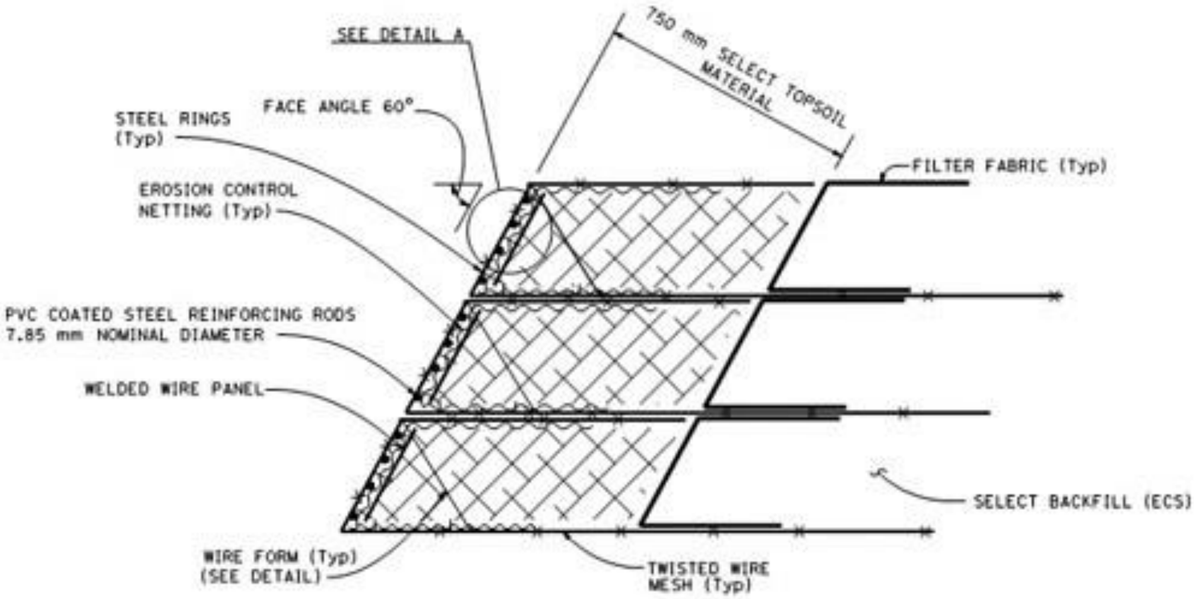
Introduction

Slopes steeper than 1:1 (H:V) will not reliably support vegetation and require a more permanent confinement technique than Rolled Erosion Control Products (RECP). A wire mesh confinement system provides additional shear strength necessary to hold non-vegetated fill material in place. Key features include:

- Structural backfill material is placed in a double twisted wire mesh enclosure with an articulated front face that can be set to match the desired slope angle
- The bottom of the confinement system can function as a geosynthetic reinforcement layer which enhances slope stability
- Local Topsoil or select material is typically used at the slope to support sustainable vegetative growth
- Rolled Erosion Control Product (RECP) Netting is placed inside the confinement system to prevent release of topsoil through the face
- Welded Wire Confinement System is also known as Embankment Confinement System

When to Use This Treatment

- Fill or reconstructed cut slopes that are between 1.5:1 (H:V) and 0.5:1 (H:V).
- Coordinate the use of this treatment with the [Division of Engineering Services (DES) Office of Geotechnical Services](), which may prepare a Geotechnical Design Report for slopes greater than 2:1 (H:V)



Benefits

- Provides immediate slope reinforcement
- Creates slope breaks that shorten slope length and reduce runoff velocities
- Increases infiltration rates on dry sites
- Provides for vegetation establishment, cover, and natural recruitment

Limitations

- Unsuitable for slopes with limited equipment access
- Must have solid footing

Technical Design Tips

- Establishment of vegetation is difficult on slopes steeper than 1:1 (H:V), and extremely difficult on slopes that exceed 0.5:1 (H:V)
- Maximum slope gradient of 0.5:1 (H:V) has been used in extreme cases for slope tie-ins to natural grades

Consider Using With

To effectively treat sites with poor soils (compacted, sterile or poorly draining), consider combining this treatment with:

- Local Topsoil

- Incorporate Materials
- Compost

Plans and Details

- Nonstandard Detail - Erosion Control (Wire Mesh Confinement)

Updated: February 12, 2019

Annex 13: Suspended solids concentrations (SSC): percent of time > 1, >2 and >5 mg/l

Percentage of time in which SSC is above 1, 2 and 5 mg/l (1 month)
(Unmitigated impact)

No color: no impact
Green: slight impact
Yellow: minor impact
Orange: moderate impact
Red: major impact

Patchreef 1	>1 mg/L	>2 mg/L	> 5 mg/L	
Construction (Phase 2.1)	0	0	0	(max = 0,1 mg/L)
Construction (Phase 2.5)	0	0	0	(max = 0,2 mg/L)
Phase 1 of dredging (without siltscreen)	0	0	0	(max = 0,3 mg/L)
Phase 1 of dredging (with siltscreen)	0	0	0	
Phase 2 of dredging (incl. approach channel)	0	0	0	(max = 0,3 mg/L)
Patchreef 2	>1 mg/L	>2 mg/L	> 5 mg/L	
Construction (Phase 2.1)	0	0	0	(max = 0,3 mg/L)
Construction (Phase 2.5)	18	14	0	(max = 4,4 mg/L)
Phase 1 of dredging (without siltscreen)	1	0	0	(max = 1,2 mg/L)
Phase 1 of dredging (with siltscreen)	0	0	0	
Phase 2 of dredging (incl. approach channel)	11	1	0	(max = 2,3 mg/L)
Patchreef 3	>1 mg/L	>2 mg/L	> 5 mg/L	
Construction (Phase 2.1)	0	0	0	(max = 0,4 mg/L)
Construction (Phase 2.5)	0	0	0	(max = 0,7 mg/L)
Phase 1 of dredging (without siltscreen)	0	0	0	(max = 0,6 mg/L)
Phase 1 of dredging (with siltscreen)	0	0	0	
Phase 2 of dredging (incl. approach channel)	0	0	0	(max = 0,7 mg/L)
Patchreef 4	>1 mg/L	>2 mg/L	> 5 mg/L	
Construction (Phase 2.1)	6	0	0	(max = 1,3 mg/L)
Construction (Phase 2.5)	0	0	0	(max = 0,6 mg/L)
Phase 1 of dredging (without siltscreen)	0	0	0	(max = 0,6 mg/L)
Phase 1 of dredging (with siltscreen)	0	0	0	
Phase 2 of dredging (incl. approach channel)	0	0	0	(max = 0,7 mg/L)
Greer Gut	>1 mg/L	>2 mg/L	> 5 mg/L	
Construction (Phase 2.1)	0	0	0	(max = 0,1 mg/L)
Construction (Phase 2.5)	0	0	0	(max = 0,4 mg/L)
Phase 1 of dredging (without siltscreen)	0	0	0	(max = 0,4 mg/L)
Phase 1 of dredging (with siltscreen)	0	0	0	
Phase 2 of dredging (incl. approach channel)	0	0	0	(max = 0,4 mg/L)

Percentage of time in which SSC is above 1, 2 and 5 mg/l (1 month)
(Mitigated impact)

Patchreef 1	>1 mg/L	>2 mg/L	> 5 mg/L	
Construction (Phase 2.1)	0,0	0,0	0,0	(max = 0.02 mg/L)
Construction (Phase 2.5)	0,0	0,0	0,0	(max = 0.04 mg/L)
Phase 1 of dredging (without siltscreen)	0,0	0,0	0,0	(max = 0.14 mg/L)
Phase 1 of dredging (with siltscreen)	0,0	0,0	0,0	
Phase 2 of dredging (incl. approach channel)	0,0	0,0	0,0	(max = 0.16 mg/L)
Patchreef 2	>1 mg/L	>2 mg/L	> 5 mg/L	
Construction (Phase 2.1)	0,0	0,0	0,0	(max = 0.05 mg/L)
Construction (Phase 2.5)	0,0	0,0	0,0	(max = 0.73 mg/L)
Phase 1 of dredging (without siltscreen)	0,0	0,0	0,0	(max = 0.58 mg/L)
Phase 1 of dredging (with siltscreen)	0,0	0,0	0,0	
Phase 2 of dredging (incl. approach channel)	0,5	0,0	0,0	(max = 1.15 mg/L)
Patchreef 3	>1 mg/L	>2 mg/L	> 5 mg/L	
Construction (Phase 2.1)	0,0	0,0	0,0	(max = 0.07 mg/L)
Construction (Phase 2.5)	0,0	0,0	0,0	(max = 0.12 mg/L)
Phase 1 of dredging (without siltscreen)	0,0	0,0	0,0	(max = 0.28 mg/L)
Phase 1 of dredging (with siltscreen)	0,0	0,0	0,0	
Phase 2 of dredging (incl. approach channel)	0,0	0,0	0,0	(max = 0.37 mg/L)
Patchreef 4	>1 mg/L	>2 mg/L	> 5 mg/L	
Construction (Phase 2.1)	0,0	0,0	0,0	(max = 0.22 mg/L)
Construction (Phase 2.5)	0,0	0,0	0,0	(max = 0.10 mg/L)
Phase 1 of dredging (without siltscreen)	0,0	0,0	0,0	(max = 0.29 mg/L)
Phase 1 of dredging (with siltscreen)	0,0	0,0	0,0	
Phase 2 of dredging (incl. approach channel)	0,0	0,0	0,0	(max = 0.37 mg/L)
Greer Gut	>1 mg/L	>2 mg/L	> 5 mg/L	
Construction (Phase 2.1)	0,0	0,0	0,0	(max = 0.02 mg/L)
Construction (Phase 2.5)	0,0	0,0	0,0	(max = 0.06 mg/L)
Phase 1 of dredging (without siltscreen)	0,0	0,0	0,0	(max = 0.18 mg/L)
Phase 1 of dredging (with siltscreen)	0,0	0,0	0,0	
Phase 2 of dredging (incl. approach channel)	0,0	0,0	0,0	(max = 0.21 mg/L)

Annex 14: RWS memo – Measurements of currents and OBS at Black Rocks harbour site

Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

To: [redacted], Saba Black Rock project

Rijkswaterstaat Grote Projecten en Onderhoud
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Datum
18 mei 2022

memo

Current temperature and total suspended solids, measurements August-November 2021

Summary

In relation with the construction of a new harbor at the Black Rock location in Saba, current and turbidity measurements have been executed in front of the future harbor entrance.

The objective of these measurements is to obtain a clear understanding of the currents that are to be anticipated near the harbor and the variation in suspended solids concentrations that are present in the water column.

Suspended solids and water temperature are important abiotic parameters in the water quality requirements for healthy reef systems. As such a clear understanding of the natural fluctuation of the suspended solids concentration will assist in defining "baseline and boundary conditions" in which the construction of the harbor is to be created.

In this memo, the measurements executed in the period August-November 2021 and the analysis of this data will be presented. This analysis results in expected current velocities and in the range of suspended solids concentrations that are found near the harbor entrance.
The range of currents (depth average) during the measurement period ranged between 0 and 0.3 m/s. On average the current was 0.1 m/s. The daily variation was mainly tidal and a diurnal tidal effect was visible in the data. The Total Suspended Solids (TSS) values were estimated from the measured FTU values and acoustic backscatter, and is 25 mg/l on average, with a range between 0-80 mg/l (99%).

In this memo the measurements will be presented followed by an analysis of the currents, the measured FTU values and the translated acoustic backscatter to FTU values.

The measurement

The equipment used for these measurements was a Nortek Aquadopp 2 Mhz ADCP in combination with a Seapoint turbidity meter that was connected to the Aquadopp. The analog turbidity meter was sampled at the same frequency as the ADCP. The technical specifications of both instruments can be found in the appendix.
The instruments were mounted against a rock. The local water depth (from the top of the rock) was 7 m, the surrounding sandy bottom was approximately 8 m deep. The location of the measurements is indicated if figure 1, which is directly south of the planned Black Rocks harbour development.

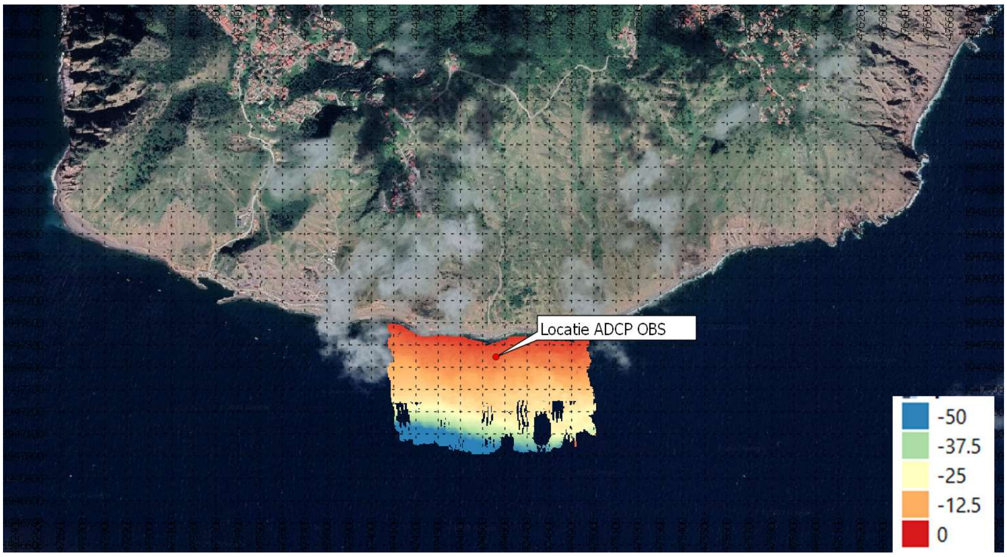


Figure 1 Location of equipment

The measurements:

Water level and temperature

The measured water levels (or actually: the water column above the sensor of the instrument) and the recorded water temperatures are presented in figure 2 and in the appendix. The pressure and temperature sensors are located approximately 7 m below the water surface. As can be seen in figure 3 the temperatures shows a daily fluctuation which is not related to the tide but to the time only, the temperatures ranges between 28.5 and 30.5 °C, the maximum temperatures are measured between 14:00-15:00 and the lowest temperatures between 5:00 and 7:00.

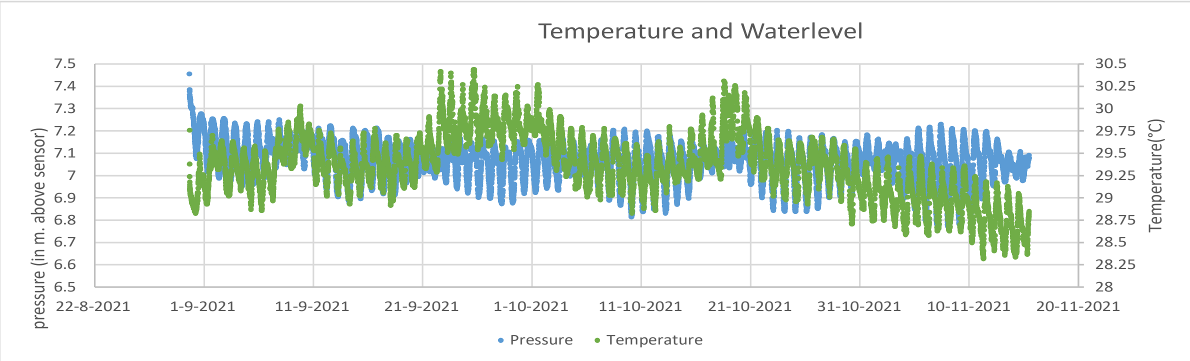


Figure 2 Temperature and water level recording in the period September-November 2021

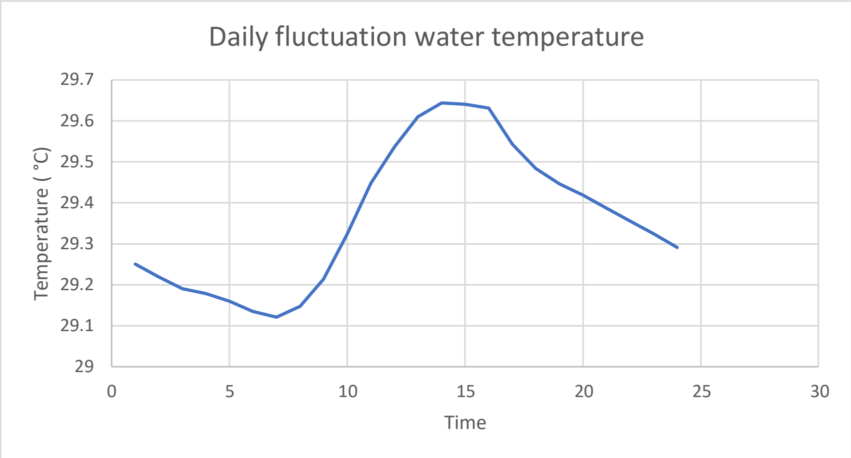


Figure 3 Daily fluctuation of water temperature in the period September- November 2021

Current

The ADCP measures currents using an acoustic doppler principle. Details of its working and its limitations can be found in the appendix and in:
https://www.nortekgroup.com/assets/software/N3015-031-ComprehensiveManual_ADCP_1118.pdf

During the period September -November the current measurements have been obtained. A typical situation is which the current is partly dominated by wind is presented in figure 4, 5 and 6. In these figures the current condition close to the bottom (and instrument), halfway the water depth and near the surface are presented. The full time series of the conditions halfway the water column are presented in the appendix. It can be seen in these figures that the (wind driven) currents near the surface are much larger than the near bottom velocities. The tidal impact on the currents (visible in the change of direction) is more pronounced in the bottom and near bed velocities.

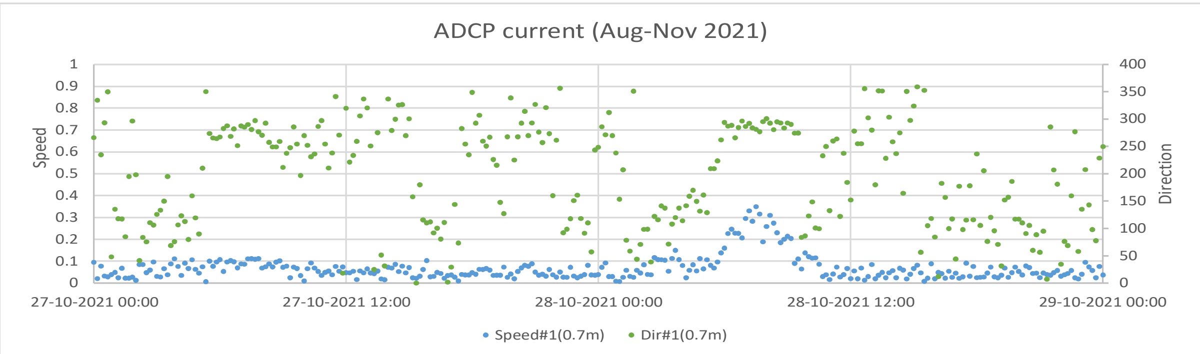


Figure 4 Near bottom current October 27nd -29th 2021

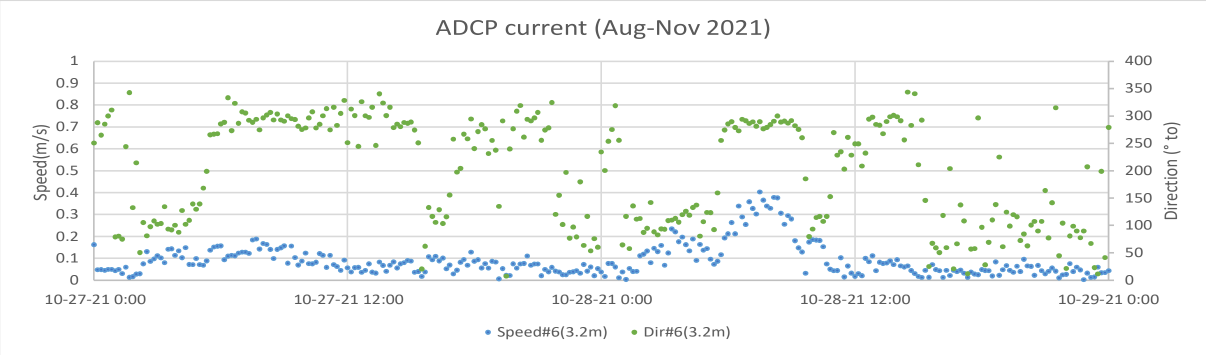


Figure 5 Mid depth current October 27nd -29th 2021

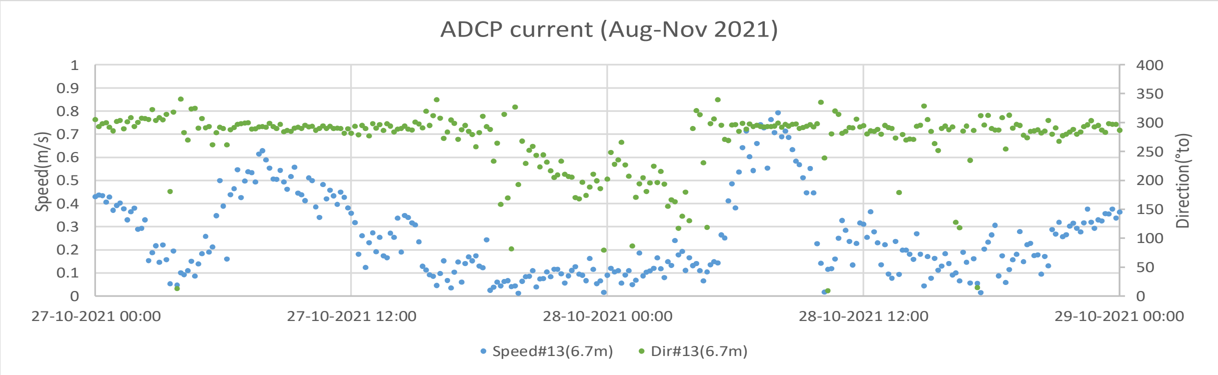


Figure 6 Currents 1 m below the surface October 27nd -29th 2021

The velocities at approximately halfway the water column are analyzed on the tidal impact. The results are presented in table 1. For this analysis the division is made in positive currents that flow eastward and negative currents that flow westward. There is a small "net" current in western direction (3 cm/s) and approximately half of the current fluctuations are tidal related (5-6 cm/s). It is remarkable that the tidal current velocities are dominated by the semidiurnal component "M2". The tidal water levels are dominated by the diurnal components (O1-K1).

The statistics of the bottom, mid-depth and surface currents are presented in table 2. From these figures it becomes clear that 90% of the time the mid depth and bottom currents are smaller than 0.15 m/s and that the surface currents are dominated by the influence of wind and slightly larger in magnitude.

Results of analysis									
Average level : -2.9									
The standard deviation of the observations is: 9.31									
The standard deviation of the hindcast: 5.95									
The standard deviation of the difference between the observed and hindcasted tide is: 7.15									
Name	Ampl(cm/s	Phase(°)	Freq(°/h)	u(½)	f(½)				
M2	6.26	352.1	28.9841	358.08	0.984				
N2	2.48	322	28.43973	358.08	0.984				
2MK3	1.69	346.3	42.92714	3.57	1.027				
2SM	1.53	22.3	2.031792	3.85	0.968				
MM	1.24	119.7	0.544375	0	0.943				
MN4	1.16	328.8	57.42383	356.15	0.968				
O1	1.13	3.3	13.94304	8.62	1.098				
M4	1.02	350	57.96821	356.15	0.968				
K1	0.96	284.5	15.04107	352.58	1.061				
S2	0.96	347.7	30	0	1				

Table 1 Tidal impact on the current

Count of Speed#1(0.7m)	Column Labels													
Row Labels	(blank)	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-360	Grand Total
(blank)														
0-0.05		2.92%	2.33%	3.34%	4.12%	3.22%	2.86%	3.07%	3.45%	4.36%	5.42%	3.85%	3.05%	42.00%
0.05-0.1		0.70%	1.19%	2.94%	4.74%	3.33%	1.90%	2.02%	3.36%	6.95%	10.50%	5.12%	1.38%	44.13%
0.1-0.15		0.01%	0.05%	0.49%	1.74%	0.89%	0.19%	0.12%	0.31%	1.85%	4.17%	1.41%	0.10%	11.32%
0.15-0.2				0.04%	0.22%				0.01%	0.27%	1.25%	0.11%		1.89%
0.2-0.25					0.01%					0.03%	0.36%	0.01%		0.41%
0.25-0.3											0.14%	0.02%		0.15%
0.3-0.35											0.10%			0.10%
Grand Total		**3.62%**	**3.57%**	**6.80%**	**10.83%**	**7.43%**	**4.95%**	**5.21%**	**7.13%**	**13.46%**	**21.94%**	**10.52%**	**4.54%**	**100.00%**

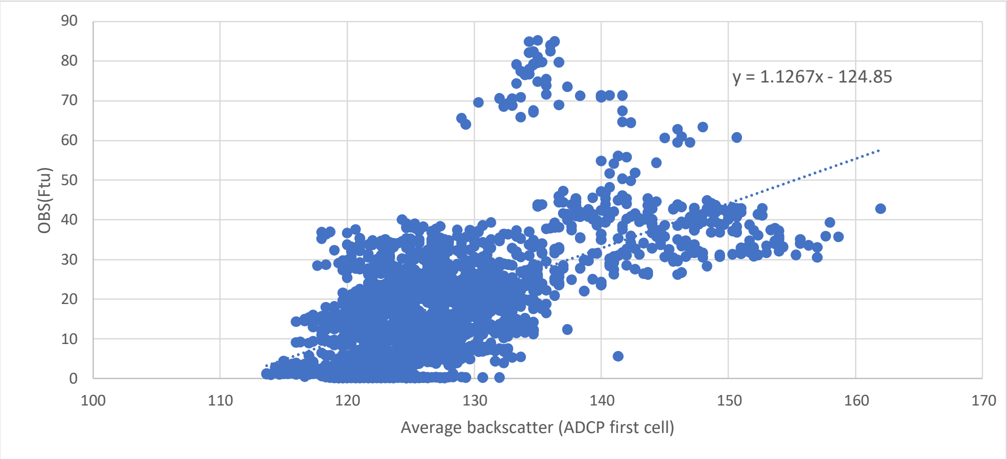
Count of Speed#7(3.7m)	Column Labels													
Row Labels	(blank)	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-360	Grand Total
(blank)														
0-0.05		2.00%	1.75%	2.11%	2.91%	1.92%	1.58%	1.97%	1.99%	2.98%	4.21%	3.05%	2.18%	28.66%
0.05-0.1		0.55%	0.62%	2.60%	5.66%	2.79%	0.67%	0.60%	1.50%	4.74%	11.93%	6.00%	1.24%	38.90%
0.1-0.15			0.01%	0.90%	4.57%	1.18%	0.05%	0.03%	0.16%	2.08%	10.27%	3.33%	0.08%	22.65%
0.15-0.2				0.08%	2.21%	0.29%			0.01%	0.23%	3.99%	0.60%		7.40%
0.2-0.25				0.04%	0.51%	0.07%				0.01%	0.85%	0.10%		1.57%
0.25-0.3					0.06%						0.40%	0.04%		0.50%
0.3-0.35					0.01%						0.22%			0.23%
0.35-0.4											0.09%			0.09%
Grand Total		**2.55%**	**2.39%**	**5.74%**	**15.93%**	**6.26%**	**2.30%**	**2.59%**	**3.66%**	**10.04%**	**31.94%**	**13.10%**	**3.50%**	**100.00%**

Count of Speed#12(6.2m)	Column Labels													
Row Labels	(blank)	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-360	Grand Total
(blank)														
0-0.05		0.32%	0.38%	0.37%	0.73%	0.65%	0.68%	0.85%	1.25%	1.23%	1.26%	0.70%	0.39%	8.80%
0.05-0.1		0.18%	0.14%	0.32%	1.05%	1.13%	0.74%	0.85%	1.84%	4.19%	4.23%	1.18%	0.21%	16.06%
0.1-0.15			0.01%	0.14%	0.93%	0.60%	0.13%	0.12%	0.59%	5.81%	8.20%	0.70%	0.02%	17.24%
0.15-0.2				0.01%	0.48%	0.19%		0.03%	0.08%	5.58%	12.32%	0.32%	0.02%	19.01%
0.2-0.25					0.33%	0.01%				3.80%	14.21%	0.12%		18.46%
0.25-0.3					0.19%	0.03%				1.84%	10.27%	0.03%		12.35%
0.3-0.35					0.05%					0.38%	5.08%	0.01%		5.52%
0.35-0.4					0.04%	0.01%				0.05%	1.63%			1.73%
0.4-0.45					0.04%						0.46%			0.50%
0.45-0.5											0.23%			0.23%
0.5-0.55											0.09%			0.09%
0.55-0.6											0.01%			0.01%
Grand Total		**0.50%**	**0.52%**	**0.84%**	**3.83%**	**2.61%**	**1.55%**	**1.84%**	**3.76%**	**22.89%**	**57.96%**	**3.06%**	**0.63%**	**100.00%**

Table 2 Probability of occurrence of the combination of current speed and direction for bottom (top), mid-depth (middle) and surface (lower table), for the period September-November 2021

Optical backscatter/ ADCP amplitudes and total suspended solids

Next to the ADCP a Seapoint optical backscatter sensor has been mounted. This OBS sensor detects light scattered by suspended particles. In general these sensors are sensitive for marine growth and long duration recordings could be effected.
In this case we have an additional sensor that could be used to indicate the variations in optical backscatter during the full period. For this purpose the acoustic backscatter of the ADCP has been correlated with the recorded data from the OBS during the first 10 days. This correlation is presented in figure 7



Figuur 7 Relation between recorded OBS values and ADCP backscatter amplitude.

Based on this relation the full period FTU values and the FTU based on the ADCP data has been presented in the appendix.

The relation between FTU and the amount of sediment in water (TSS in mg/l) is normally based on a calibration between local obtained water samples near the recording instrument on selected moments.
The calibration between FTU and TSS can also be based on bottle sample test in which local sediments are added to the sample and the resulting FTU values are then measured in the bottle.

Based on the article of Ross Jones (2011) *Environmental effects of the cruise tourism boom: sediment resuspension from cruise ships and the possible effects of increased turbidity and sediment deposition on corals (Bermuda*) see:
https://www.ingentaconnect.com/content/umrsmas/bullmar/2011/00000087/00000003/art00022,
a relation between the FTU values and the anticipated suspended solids concentrations is obtained.

From the work of Ross Jones in a similar tropical environment it is estimated that a reasonable relation between TSS and FTU can be obtained as follows; TSS(mg/l)=1.6*FTU. In general this relation is related to grainsize and particle type.

Similar linear relations are found elsewhere, in different environments (river, estuaries and rainfall sewer systems) in those situations linear multiplication factor ranges between 0.8 and 2.5. The factor 1.6 can therefore be seen as an representative average.

The resulting statistics of the TSS values as recorded in the period September-November 2022 can be found in table 3. The period average TSS value seems to be 25 mg/l (between 0-80 mg/l)

Tss values (mg/l)	occurence frequency class	exceedance frequency lower boundary
0-10	10.0%	100.0%
10-20	29.3%	90.0%
20-30	24.8%	60.7%
30-40	14.3%	35.9%
40-50	8.8%	21.6%
50-60	6.0%	12.7%
60-70	3.9%	6.8%
70-80	2.0%	2.9%
80-90	0.6%	0.9%
90-100	0.1%	0.3%
100-110	0.1%	0.2%
110-120	0.0%	0.1%
120-130	0.0%	0.0%

Table 3 TSS values in the period September-November 2021

Discussion, conclusion and recommendation.

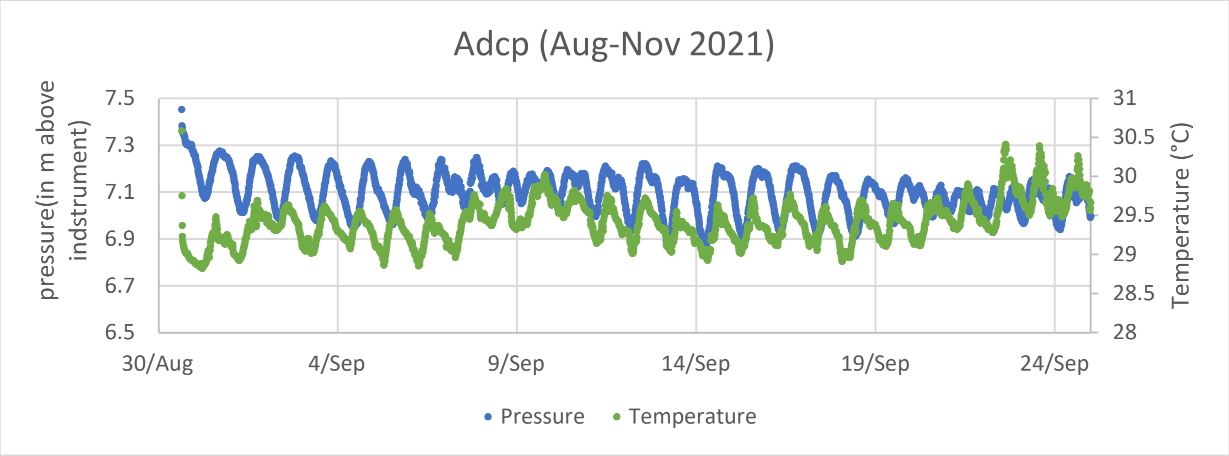
Measurements of currents and optical backscatter have been done. The current measurements are showing a clear picture in which the currents are limited (< 20 cm/s), partly related to the tide and near the surface dominated by the winds and slightly larger.

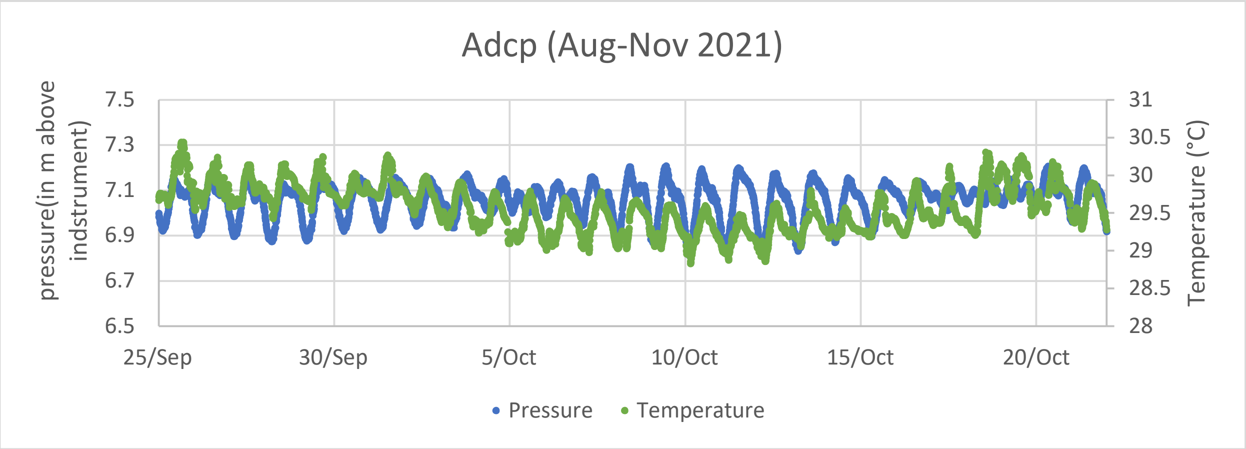
The optical backscatter figures and especial the resulting TSS values are showing a diffuse situation. The measured OBS values can be effected by marine growth or other obstructions of the optical system. Therefore we used the backscatter values of the ADCP as an additional sensor. There seems to be a reasonable correlation between the obtained OBS values and the acoustic backscatter values during the first 14 days (see time series in the appendix). However the ADCP backscatter values are averaging out the OBS values both on the low and on the high recordings.

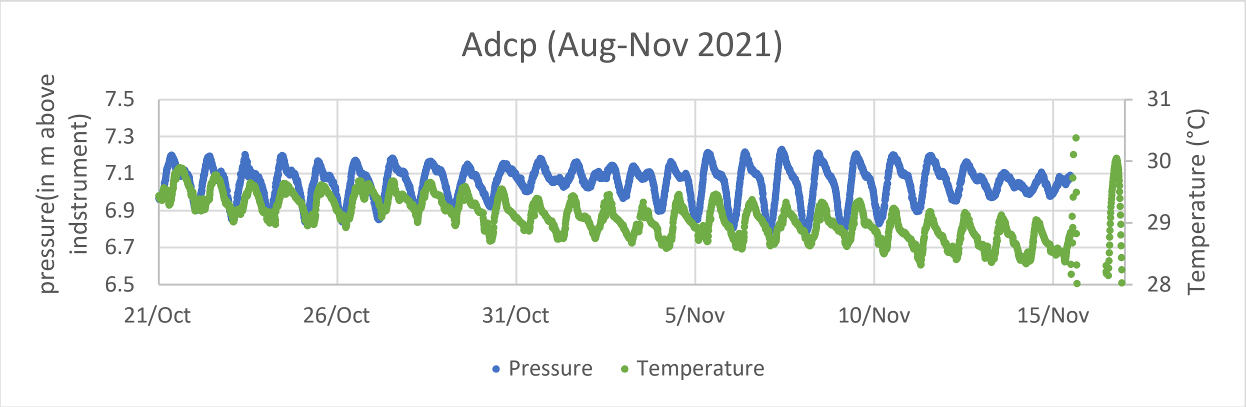
The resulting (time average) TSS value is 25 mg/l. This is based on a relatively short measurement period. During this period, typical wind, wave and tidal conditions occurred which are representative for the general year-round MetOcean conditions at this location, with the exception of winter storms and hurricanes. For this reason, it is expected that the measured TSS values (average and range) are also representative for the typical year-round TSS values.

It is recommended to validate the OBS and ADCP measurements by additional, longer-term measurements. These measurements should be combined with water sample analysis in which local sediments are added to a fixed volume of water and the OBS values measured. This is to provide a better correlation between FTU and backscatter and TSS. Further during the (long period) recording of a combination of ADCP and OBS, it is advised that the OBS sensor is cleaned on a weekly interval.

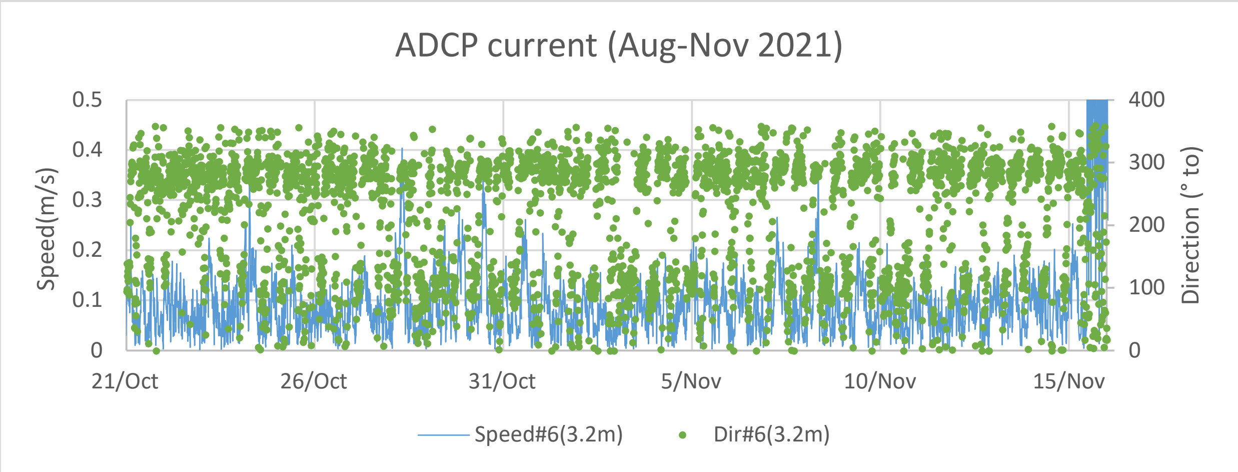
APPENDICES

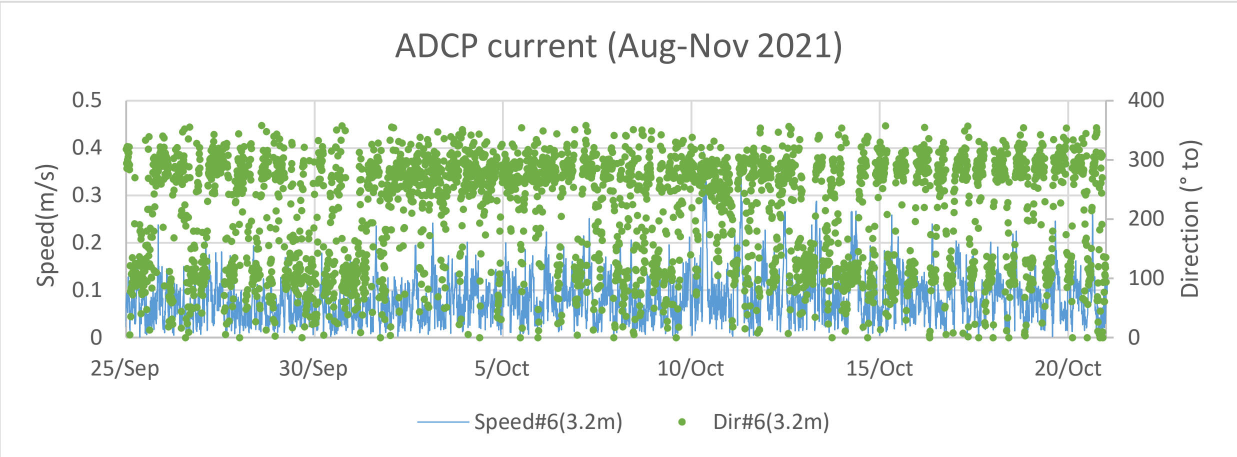


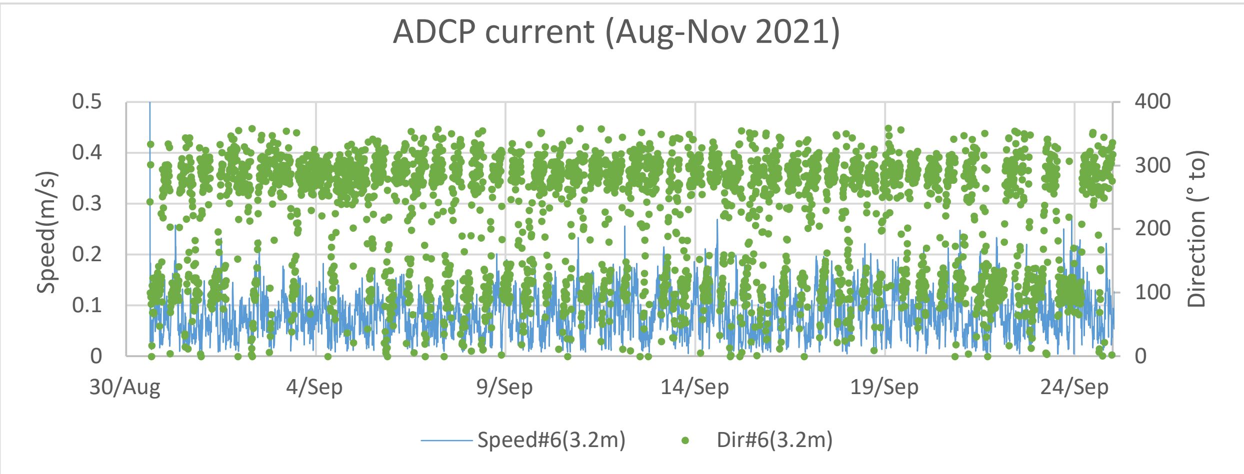




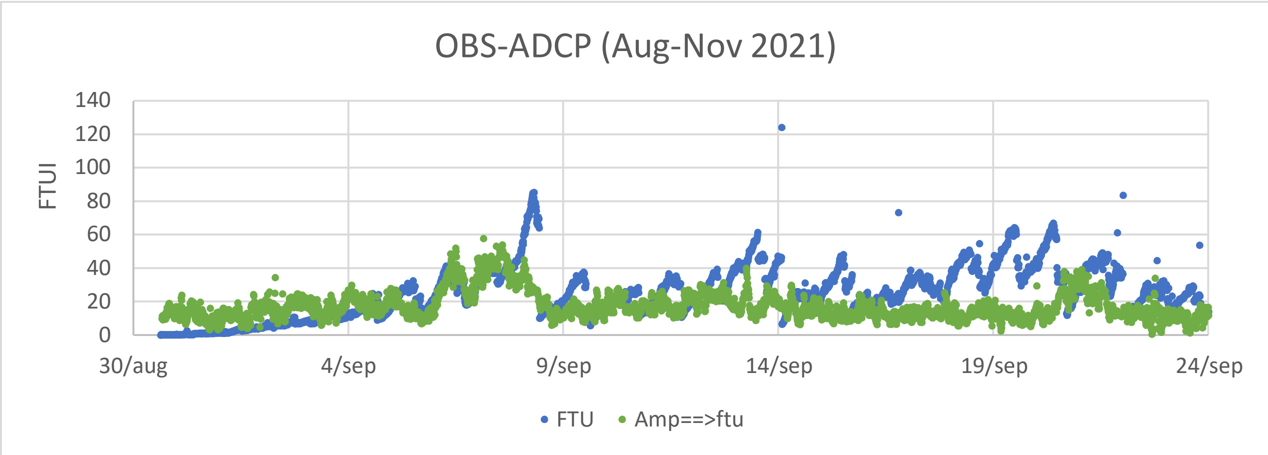
Water level and temperature

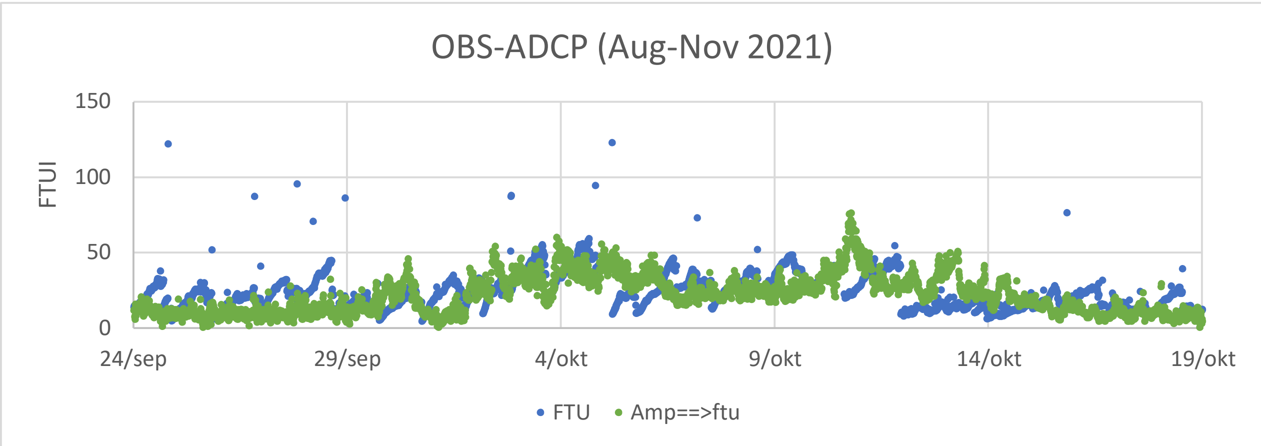


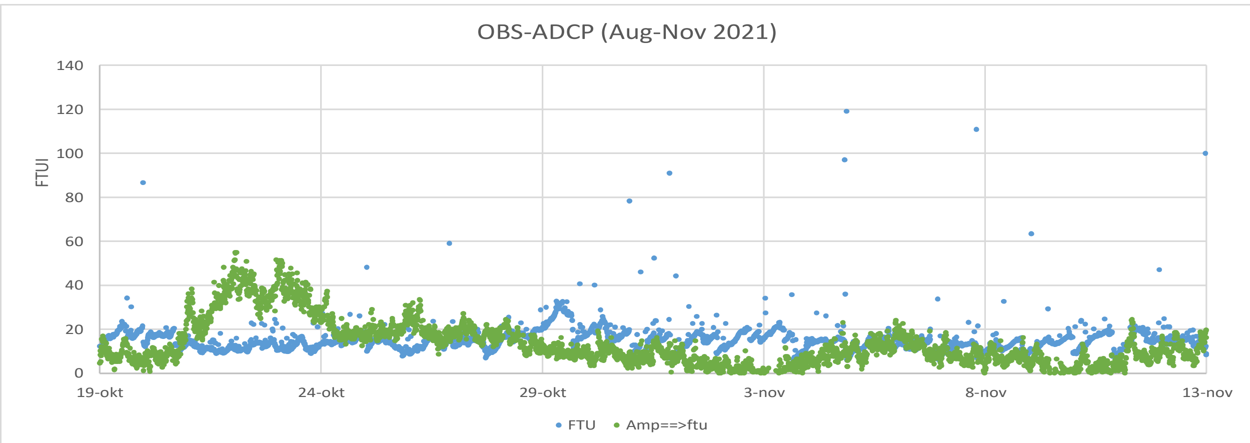




Current speed and direction



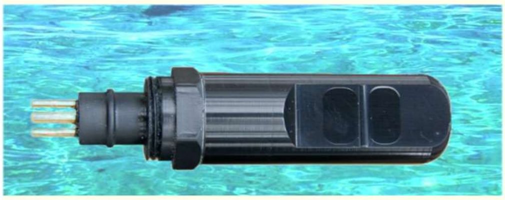




Total suspended solids, acoustic backscatter and ftu

Seapoint Turbidity Meter

Download pdf *Datasheet* *or* *User Manual*



DESCRIPTION

The **Seapoint Turbidity Meter** detects light scattered by particles suspended in water, generating an output voltage proportional to turbidity or suspended solids. The low power requirements make it ideal for applications where battery drain is a concern. Range is selected by two digital lines which can be hard wired or microprocessor controlled, thereby choosing the appropriate range and resolution for measurement of extremely clean to very turbid waters. The offset voltage is within 1 mV of zero and requires no adjustment across gains. The unique optical design confines the sensing volume to within 5 cm of the sensor allowing near-bottom measurements and minimizing errant reflections in restricted spaces. The sensor is easily interfaced with data acquisition packages; a 5 ft pigtail is supplied. Custom configurations are available.

FEATURES

- Very low power requirements
- Small size
- 6000 m depth capability
- Optically confined sensing volume
- Insensitive to ambient light
- Linear output over more than 5 decades
- Four programmable ranges
- Optical feedback compensates for temperature coefficient and aging of optical components
- Very low power requirements
- Very low offset voltage does not require adjustment
- Interfaces easily with data acquisition systems
- Rugged, corrosion-free materials
- Pin compatible with Seapoint Chlorophyll Fluorometer and Seapoint Rhodamine Fluorometer

APPLICATIONS

- Profiling, Moored, Towed, or In-Line Measurements
- Pollution/Runoff Monitoring
- Dredging and Construction Monitoring
- Water and Wastewater Quality
- Sediment Transport and Settling Studies
- Ocean Science and Research
- Limnological Studies
- Hydrothermal Vent Detection
- Crude Oil Detection

SPECIFICATIONS

• Power Requirements:	7-20 VDC, 3.5 mA avg., 6 mA pk.
• Output	0-5.0 VDC
• Output Time Constant	0.1 sec.
• RMS Noise	< 1 mV
• Output Impedance	1000 ohms
• Power-up Transient Period	< 1 sec
• Light Source Wavelength	880 nm
• Sensing Distance (from windows)	< 5 cm (approx.)
• Linearity	< 2% deviation 0-1250 FTU, <5% deviation 0-1600 FTU

• Sensitivity/Range

** (output is non-linear above 750 FTU)

Gain	Sensitivity (mV/FTU)	Range (FTU)
100x	200	25
20x	40	125
5x	10	500
1x	2	4000**

• Temperature Coefficient	< 0.05%/°C
• Depth Capability	6000 m (19,685 ft)
• Weight (dry)	86 g (3.0 oz)
• Operating Temperature	0°C to 65°C (32°F to 149°F)
• Material	Rigid polyurethane

CURRENT PROFILER

Aquadopp Profiler 2 MHz

Small and compact, short-range current profiling; option for PUV wave measurements

The Aquadopp Profiler is a highly versatile Acoustic Doppler Current Profiler (ADCP) available in four profiling range options, from < 1 m to > 85 m. Designed for simple yet powerful operation, this current profiler is packed with features used by engineers and researchers to enable accurate and effective hydrodynamic data collection in a variety of environmental conditions.

CURRENT PROFILER

Aquadopp Profiler 2 MHz

Highlights

- ☑ Up to 10 m current profiling range
- ☑ Optional right-angle head
- ☑ PUV-based directional wave measurements

Applications

- ☑ Near-bed current profiles with fine vertical resolution
- ☑ Mean flow measurements with high focus on ease of use and simplicity
- ☑ Measurements in flow regimes with strong variations in flow speeds
- ☑ Projects with needs for both high-resolution and normal-range current measurements
- ☑ Measurements of combinations of waves and currents
- ☑ Studies of deep-water currents
- ☑ Studies of tidal currents
- ☑ Mounted on surface buoys
- ☑ Suitable for wave buoys

CURRENT PROFILER

Aquadopp Profiler 2 MHz

Technical specifications

Water velocity measurements	
Maximum profiling range	4-10 m
Cell size	0.1-2 m
Minimum blanking	0.05 m
Maximum number of cells	128
Measurement cell position	N/A
Default position (along beam)	N/A
Velocity range	±10 m/s
Accuracy	±1% of measured value ±0.5 cm/s
Velocity precision	Consult instrument software
Maximum sampling rate(output)	1 Hz
Internal sampling rate	23 Hz
Echo intensity (along slanted beams)	
Sampling	Same as velocity
Resolution	0.45 dB
Dynamic range	90 dB
Transducer acoustic frequency	2 MHz
Number of beams	3
Beam width	1.7°
HR option	
Maximum profiling range	3 m
Cell size	7-150 mm
Minimum blanking	0.03 m
Maximum number of cells	128

CURRENT PROFILER

Aquadopp Profiler 2 MHz

Analog inputs	
Resolution	16-bit A/D
Data recording	
Capacity	9 MB, can add 4/16 GB
Data record	9*Ncells + 32 bytes
Diagnostics record	N/A
Wave record	Nsamples * 24 + 60 bytes
Mode	Stop when full (default) or wrap mode
Real-time clock	
Accuracy	±1 min/year
Backup in absence of power	4 weeks
Data communications	
I/O	RS-232 or RS-422
Communication baud rate	300-115200 Bd
Recorder download baud rate	600/1200 kBd for both RS-232 and RS-422
User control	Handled via "Aquadopp" software, ActiveX®function calls, or direct commands with binary or ASCII data output
Connectors	
Bulkhead	MCBH-8-FS
Cable	PMCIL-8-MP on 10 m polyurethane cable
Software	
Functions	Deployment planning, instrument configuration, data retrieval and conversion (for Windows®)
Power	
DC input	9-15 V DC
Maximum peak current	3 A
Avg. power consumption	0.03 W
Sleep current	< 100 µA

CURRENT PROFILER

Aquadopp Profiler 2 MHz

HR option	
Range/Velocity limitations	Product of profiling range and velocity should not exceed 0.5 m2/s (2 MHz system)
Accuracy	±1% of measured value ±0.5 cm/s
Max. sampling rate	1 Hz (continuous mode,)8 Hz (burst mode)"
Z-Cell option	
Cell zero acoustic frequency	N/A
Maximum profiling range	N/A
Number of beams	N/A
Sensors	
Temperature:	Thermistor embedded in head
Temp. range	-4 to +40 °C
Temp. accuracy/resolution	0.1 °C/0.01 °C
Temp. time response	10 min
Compass:	Magnetometer
Accuracy/resolution	2°/0.1° for tilt < 20°
Tilt:	Liquid level
Accuracy/resolution	0.2°/0.1°
Maximum tilt	30°
Up or Down	Automatic detect
Pressure:	Piezoresistive
Range	0-100 m (inquire for options)
Accuracy/precision	0.5% FS / 0.005% of full scale
Analog inputs	
No. of channels	2
Supply voltage to analogoutput devices	Three options selectable through firmware commands: 1) Battery voltage/500 mA, 2) +5 V/250 mA, 3) +12 V/100 mA
Voltage input	0-5 V

CURRENT PROFILER

Aquadopp Profiler 2 MHz

Power	
Transmit power	0.3-20 W, 3 adjustable levels
Batteries	
Battery capacity	1) 50 Wh (alkaline or Li-ion), 2) 165 Wh (lithium), 3) Single or dual
New battery voltage	13.5 V DC (alkaline)
Environmental	
Operating temperature	-5 to +40 °C
Storage temperature	-20 to +60 °C
Shock and vibration	IEC 721-3-8
EMC approval	IEC 61000
Depth rating	300 m, (3000 m and 6000 m option)
Materials	
Standard model	POM and polyurethane plastics with titanium fasteners
Dimensions	
Maximum diameter	75 mm
Maximum length	~550 mm (single battery), +110 mm (double battery) depending on head configuration
Weight	
Weight in air	2.2 kg
Weight in water	0.2 kg
Options	

1) Alkaline, lithium or Li-ion external batteries, 2) Inquire for different head configurations

Annex 15: Summary EIA Fort Bay including comparison Fort Bay – Black Rocks

Summary EIA Fort Bay

Introduction

Hurricanes Irma and Maria caused significant damage to the Fort Bay Harbor on Saba in 2017. A complete rebuild of the secondary breakwater and an extension of the primary breakwater are therefore required. With this necessity, an opportunity arose to reach multiple longer-term goals in a cost-efficient way. The new breakwaters should enable a better separation of large (cargo) traffic from other activities, like fishing, ferries, dive boats and pleasure boats. Overall, a larger usable area will be created in the harbor with the new breakwaters. By improving accessibility and making the harbor more attractive, more tourism traffic will be generated, thereby improving the possibilities for economic development.

This Environmental Impact Assessment (EIA) is a document aimed to support the decision making for the harbor renovation project. It is a legal obligation based on the national Law on maritime management and the Saba Ordinance on the marine environment.

The objectives of the EIA are:
- to assess the natural values in the harbor area (both marine and terrestrial);
- to assess the environmental situation in the harbor area (both marine and terrestrial);
- to assess the environmental and ecological impacts of the harbor renovation project in Fort Bay;
- to define mitigation measures for these impacts.

Main features of harbor renovation project

The main elements of the harbor renovation project (anticipated, "voorgenomen activiteit") are two new breakwaters. The whole project however comprises of a number of associated projects. In chronological order the following project elements will be implemented:
- a new road connection to the west part of the harbor and cliff stabilization;
- the construction of the secondary breakwater, using modular caissons prepared at site, and the removal of the current breakwater;
- extension of the primary breakwater, using a cofferdam construction;
- construction of revetment (scour protection, armour rock);
- dredging of the harbor to specified depth;
- a small land reclamation west of the harbor, including a natural swimming pool, open to the sea;
- construction of harbor facilities.

Environmental impacts from these activities have been evaluated in this EIA for the anticipated project (voorgenomen activiteit). In addition, impacts have been evaluated for the following alternatives:
- construction with prefab caissons instead of modular caissons prepared at site;
- construction of both breakwaters with caissons only;
- construction of both breakwaters with cofferdams only.

Main ecological values

The area in the direct vicinity of the harbor and a part of the area between the harbor and Tent Reef was surveyed by SCF. The area can be characterized as a sandy seafloor with scattered rocks overgrown by benthic species, mainly corals and sponges. In the direct vicinity of the secondary breakwater, at the south and west side, a large number of rocks covers the seafloor. Most of the smaller boulders have no significant growth on their surfaces. The density of corals is very low (< 1% cover).
Two small colonies of *Acropora palmata* were observed and 10-15 small colonies of *Montastraea faveolata* and *Montastraea annularis*, near the secondary and primary breakwater.
The area between the harbor and Tent Reef is also characterized by a sandy seafloor and dispersed boulders with benthic growth. These boulders are mainly present in the shallow waters (1-3 meters). Densities of corals and sponges are very low (< 1% cover).
Approximately 400 meters downcurrent of the Fort Bay harbor is an unusual geological structure known as Tent Reef. Tent Reef is a favorite site for divers. Coral densities are locally higher than 25% cover.
To the east (100 m up current) some small patch reefs are present in a mainly sandy area. A number of moorings are present for diving.

Impacts and impact mitigation

Table 1 presents a high-level overview of the most important impacts per subproject of the harbor renovation. With respect to sedimentation it is important to mention that all subprojects will be carried out sequentially, except the land reclamation. The reclamation area will receive rock material and granular material from several subprojects.

Table 1: High-level overview of impacts

Impact	Subprojects					
	Road construction	Secondary breakwater	Primary breakwater	Dredging	Land reclamation	Harbor facilities
Loss of coral in footprint		☐	☐		☐	
Sedimentation turbidity	☐	☐	☐	☐	☐	
Noise			☐			
Anchoring damage		☐	☐	☐		

Loss of coral in footprint

The extension of the breakwaters and the land reclamation account for 8.000-9.000 m2 of seafloor to be covered. If a high-risk zone is defined comparable to the Black Rocks project, the footprint area (excluding the current footprint) is 2,6 ha. The seafloor consists partly of sandy bottoms and partly of rocky bottoms. The relative cover of reef building organisms (hard corals, crustose coralline algae) and other relevant reef organisms such as sponges, sea urchins, sea anemones, tube worms etc. is low (corals less than 1%), and most of this is exclusively present on boulders near the current breakwaters and west of the secondary breakwater. In this footprint area a number of colonies of protected corals of the *Montastraea* and *Acropora* genera are present, approximately 20-30 colonies. The relocation of these protected corals is included in the project. For the loss of other corals a compensation project will be set up in cooperation with the Saba Coral Nursery Project. Compensation will be in the form of re-establishing of a variety of coral species, protected and non-protected, on the boulders of the revetment of the new breakwaters.

Sedimentation

All planned marine works lead to disturbance of the sea floor and subsequent resuspension of fine sediment particles present in the top layer of the sea floor. In addition, the road construction can lead to erosion of sediments that end up in the marine environment during rainy periods.
In high concentrations, suspended solids can harm corals and sponges and other filter feeders (lower growth rates, reduced coral recruitment and in cases of severe deposition even tissue necrosis).
The seriousness of the impacts depends on a number of aspects: the presence of vulnerable species (e.g. corals), the load and quality of the sediments and the duration of the load.
Tent Reef with an abundance of coral species including protected species, is the most vulnerable area but also at greatest distance from the activities.
Risks for high loads and qualitatively unfavorable loads are present during road construction and land reclamation, because the sediments from terrestrial origin usually have higher contents of fine particles and higher contents of organic matter and nutrients. These particles reach farther and have a more negative impact than coarse mineral particles. The marine sediments of Fort Bay harbor, hydraulically a very dynamic environment, are low in fine particles and organic matter[1] and their impact will be significantly less, and mainly local, in areas with lower densities of marine benthos (the area between the harbor and Tent Reef).
Impact mitigation is important for all subprojects that lead to sedimentation, but especially for the road construction and the land reclamation. Proposed mitigation methods for road construction are: slope stabilization (75% less erosion), revegetation by seeding (90-99% less erosion) and storm water diversion. The proposed mitigation measure for the land reclamation is to install a revetment bund with a filter at the inner side of the bund before filling of the area. This structure virtually blocks all water movement, providing the conditions for settlement of fine particles.
Impact mitigation for the bed preparation for the breakwaters and dredging of the harbor basin will be by means of standing or hanging silt screens, in a closed configuration. These silt screens are less effective than “hard” sheltering structures such as a breakwater or a revetment bund with filter, but are able to reduce the concentration of suspended matter by approximately 40%. This reduction is considered sufficient because of the relatively favorable quality of the harbor sediments (low content of fines, low content of organic matter).

Noise

Impact piling can negatively impact hearing in marine organisms such as fish (including sharks), sea turtles, (deep) diving birds, whales and dolphins[2]. By a combination of technical measures and management measures the risk for these marine organisms can be mitigated effectively. The main measures are: the use of vibro-piling where possible, avoiding breeding and calving periods, and observation of marine mammals (e.g. by Saba Conservation Foundation) in combination with a stopping procedure when marine mammals enter a zone of less than 1 km from the source of noise. Also a soft start procedure, which gives marine organisms time to move away from the source of noise is effective for fish, turtles, diving birds and marine mammals. A quantitative acoustic assessment needs to be carried out to define the proper mix of mitigating measures and selecting the proper dimensions of the safety zones.
A species of interest is the Red-billed tropicbird, with colonies at Tent (400-500 meters west) and Great Level (1000 meters east). Birds of these colonies have been observed regularly at Fort Bay. Because of their foraging grounds (far away from the coast) and their foraging behavior (shallow dives) the species is not very sensitive to noise underwater. Above the water, the birds may experience disturbance from noise at their nesting sites, especially at Tent which is the nearest location and also downwind of the source of noise. As a mitigating measure, the site at Tent will be

[1] 1.3% silt and clay (Fort Bay: 2-3%) and 1.14 % organic matter (Fort Bay: 1.6%), where values in other harbors, e.g. Aruba and Curaçao are up to 60% fines and 3-21% organic matter

[2] Temporary noise induced hearing loss (TTS) and permanent noise induced hearing loss (PTS)

monitored by ornithologists (bird experts). When signs of stress are observed, the pile driving will be discontinued at 16.00 hours, the time the birds normally return from their feeding grounds.

Anchoring

Anchor lines for working barges create the risk of damage to corals and sponges. This impact is considered moderate to low since only few rocks with corals and sponges adhered are present in the direct vicinity of the harbor. As a preventive measure, a detailed anchoring plan, which demonstrates least damage, will be presented to the Government.

Impacts on protected species

Currently, there is no specific island legislation for the protection of threatened and valued species on Saba. This legislation is still in development. On the national level however, a number of species are protected through the process of dynamic reference of international conventions in the National Law on principles of nature management[3]. These species are: all sea turtles, sharks and whales and dolphins that live in Saban waters, 3 bird species (Brown Pelican, Audubon shearwater and the Roseate tern) and 4 coral species (*Acropora palmata, Acropora cervicornis, Montastraea annularis* and *Montastraea faveolata)*.
Most of these species will experience impacts by noise during pile driving. Species that live underwater (fish, sea turtles, sea mammals) or have relatively long diving times (e.g. Audubon shearwater, Brown pelican) are more vulnerable than the species that live above water and have short diving times (e.g. Roseate tern, Red-billed tropicbird). Sea turtles and sharks (which are lacking swimming bladders) are considered less vulnerable than marine mammals.
For protected corals the most important impacts are: removal from the footprint area and sedimentation.

Table 2 summarizes the most important risks for protected species, their sensitivity and the impact mitigation.

Table 2: Risks and impact mitigation protected fauna species

Protected Species	**Risk, sensitivity**	**Mitigation**
Green turtle, Hawksbill turtle	Medium sensitive to noise, able to avoid noise loads	Soft start pile driving
Whales and dolphins	Sensitive to noise, able to avoid noise loads	Soft start, zoning, observation team, stopping procedure, avoid pile driving during calving period (December-May)
Whale shark and other sharks	Medium sensitive to noise (lacking a swimming bladder), able to avoid noise loads	Soft start pile driving
Brown pelican Audubon's shearwater	Sensitive to noise, swimming underwater (*); able to avoid noise loads	Soft start pile driving
Roseate tern Red-billed tropicbird (**)	Relatively shallow divers (*), medium risk	Soft start pile driving
Corals: *Acropora palmata, A. cervicornis, Montastraea annularis* and *M. faveolata*	Corals need to be removed from footprint; Corals are sensitive to sedimentation. Risk is limited because of low densities of corals near harbor and because of low contents of organic material and fines.	Relocation of corals, re-establishment of corals. Slope stabilization, revegetation, silt screens.

(*) source: Guide to North American Birds

[3] "Wet grondslagen natuurbeheer": The most relevant international conventions cited are: Cartagena Convention and SPAW Protocol, and the Convention for the Protection of Migrating species (CMS)

(**) Strictly speaking not a protected bird however criterion species for IBA designation

Impacts by alternatives

Construction of the primary breakwater with caissons would lead to significantly less noise under water and above water and reduce the risk of impacts for marine fauna and diving sea birds. However, the primary breakwater is in deep water (> 10m) and a caisson structure (and a berm breakwater) could not be properly designed because of the extreme wave forces.
Construction of the secondary breakwater with a cofferdam structure will lead to a longer period of high noise in the area with related risks for marine fauna and birds (12-13 weeks instead of 5-6 weeks). The footprint of the combined structures will be approximately 1400 m2 less than in the anticipated project.
In view of the relatively low densities of benthic fauna in the harbor area (such as corals and sponges), as well as the reduction of impacts for marine fauna and diving sea-birds, the ecological balance can be regarded to be in favor of constructing the secondary breakwater with caissons.
Construction of the secondary breakwater with prefab caissons instead of modular caissons prepared at site will slightly reduce environmental impacts, mainly because of reduced dust generation and reduced run-off with fine particles, due to less storage of granular materials.

Legal requirements

For the planned harbor renovation the following legal requirements and obligations exist:

- a permit is required from the Dutch Minister of Infrastructure and Water Management (Law on maritime management);
- an impact assessment on marine nature and environment (this report) is required as well as on safety and archaeology (Law on maritime management);
- construction permits are required for the breakwaters (Law VROM-BES);
- an anchoring prohibition in Marine Park exists for areas with corals (Saba Marine Environment Ordinance);
- an exemption from the Executive Committee is needed, preceded by an independent environmental impact assessment (Saba Marine Environment Ordinance);
- negative impacts for protected species must be minimized (Law on nature management)[4];
- an exemption for the removal of corals from the Dutch Minister of Infrastructure (Law on nature management) is not needed since the number of corals to be removed is small and possibilities for relocation exist;
- the Saba Conservation Foundation (SCF) may define additional conditions that need to be met before, during and after the construction activities (article 15, Marine Environment Ordinance of Saba).

Conclusions

1. The two main environmental aspects of the harbor renovation project are sedimentation, and noise by impact piling. If unmitigated, sedimentation can harm benthic organisms such as corals and sponges. If unmitigated, impact piling can negatively impact hearing or lead to barotrauma (e.g. damage of swimming bladder or other tissues) in marine organisms such as fish, turtles, diving birds, whales and dolphins. Above water, noise can be a disturbing factor for Red-billed tropic bird living in two colonies near the harbor area;

[4] all sea turtles, sharks, whales and dolphins, 3 bird species (Brown Pelican, Audubon shearwater and the Roseate tern) and 4 coral species (*Acropora palmata, Acropora cervicornis, Montastraea annularis* and *Montastraea faveolata)*.

2. Tent Reef is the most sensitive area for sedimentation. The area between the harbor and Tent Reef is less sensitive, since the density of marine benthos is low in this area;
3. The marine sediments in and near the harbor have a favourable quality -concentrations of fine particles and organic matter is low- compared to other Caribbean harbors, which reduces the risk of negative impacts on corals and sponges. Mitigation of impacts by a variety of measures further reduces the risk for corals, sponges and other marine benthos;
4. Impacts from noise from pile driving such as hearing loss in marine mammals, sea turtles and diving sea birds can be mitigated effectively;
5. Red-billed tropic bird -an important bird species-, in particular a breeding colony at Tent, is considered a vulnerable species for noise above water. The colony needs to be monitored during the period of pile driving and if signs of stress are observed during piling, this activity should stop at 16.00 hours and begin no earlier than 08.00;
6. In general, impacts on protected marine and coastal fauna species can be sufficiently mitigated;
7. From an environmental point of view, constructing the secondary breakwater with caissons is preferred, because of lower noise impacts on marine fauna and sea birds and (only) slightly elevated footprint impacts.

Recommendations for Saba Harbor Authorities

It is recommended that during the period of the harbor works, the water quality (mainly affected by suspended solids, TSS) at Tent Reef be monitored on a daily basis. When values of TSS are found to be above a critical value (e.g. 5 mg/l above background) for a number of samples, additional measures can be taken such as decreasing the work intensity or installation of additional silt screens. This method, recently developed by the University of Delft in cooperation with the dredging industry is also known as “adaptive management” or “adaptive monitoring”.

The risk evaluation during the work can also be aided by using drone-imagery to better understand plume dispersion and aid adaptive management.

It is further recommended to perform a biological monitoring including an assessment of stress in corals and sponges at Tent Reef before, during and after the road construction and marine works.

It is recommended to avoid activities generating high turbidity in the coral spawning season (PIANC, 2010). This period could be selected as one month before and one month after coral spawning.

It is recommended not to apply silt screens when current velocity is above 0.5 m/s or wave heights above 1.0 m. Currents above 0.5 m/sec are rare at the south coast of Saba, but the class of wave heights occurring most often on Saba is the class of 1-1.5 meters. During the months of August through October however, the class most occurring is 0.5 to 1 meters (50-60% of the time). It is recommended to plan most of the bed preparation, excavation and land reclamation works in this period of the year.

It is recommended to use vibro-piling instead of impact piling when possible.

It is recommended to avoid pile driving during the calving period of the Humpback whale (winter months), the bottlenose dolphin (summer months) and the breeding period of important sea birds[5].

[5] The Audubon shearwater are known to be present between December and May, but do not have a distinct breeding season. The Red-billed tropicbird breeds almost year round (Boeken, 2016).

The Saba Conservation Foundation (SCF) may define additional conditions that need to be met before, during and after the construction activities, e.g. deployment of additional silt screens in case of high measurements of TSS, a stopping procedure for pile driving when marine mammals are within 1 km from the noise source.

Summary comparison Fort Bay-Black Rocks

Introduction

The process of decision making for a new harbor is a complex matter. The competent authority needs to weigh many different aspects. Besides ecological aspects, safety, security and economic aspects including tourism, social aspects including employment and aspects of physical planning need to be evaluated.
In this summary we compare the ecological and environmental impacts related to the two main alternatives for the harbor of Saba: (1) the renovation of Fort Bay Harbor and (2) the development of a new harbor at Black Rocks. With this comparison an effort is made to contribute to transparent decision making related to the harbor development.

Comparison

General comparison

In environmental and ecological terms, the construction of a new harbour at Black Rocks can be characterized as a “greenfield development”. No commercial or industrial or other structures are present in the area, which is a natural grassland area with shrubs and trees interspersed. The expansion and redevelopment of the harbour at Fort Bay can better be characterized as a “brownfield development”, i.e. a development in a location with pre-existing infrastructure and possible contamination.

At Fort Bay the project entails the extension of primary breakwater, the removal of the current secondary breakwater and reconstruction of a new, larger secondary breakwater. At Black Rocks, the project entails the construction of an entirely new harbor (landside and marine construction), including an access road and weirs for water management.

The comparison of impacts described below is based on the assumption that full mitigation of impacts (as proposed in the EIA) takes place.

Footprint, loss of vegetation and marine benthos

The total terrestrial footprint of the Fort Bay Harbor redevelopment is 3.000m2 while the footprint of the Black Rocks development is approximately 40.000m2. At Black Rocks 22.000 m2 of grass/shrub land, with relatively high ecological value, and approximately 15-20 trees need to be cleared (most of the trees are in the footprint area of the weirs). A surface area of approximately 5.000 m2 is the surface of already existing unpaved roads). The loss of natural vegetation in Fort Bay would be relatively insignificant (650 m2 of grassland for a new road at Bunker Hill).

The marine footprint of the Fort Bay redevelopment is approximately 26.000m2 (including land reclamation). At Black Rocks this area is 90.000m2. In both cases the area is including a high-risk zone where intensive work is occurring, with activity of barges and dredging vessels, anchoring etc. All colonies of protected corals (*Acropora palmata, Acropora cervicornis, Montastraea annularis* and *Montastraea faveolata*) living in the footprint areas and in the high-risk zones will be relocated to another, safe area. This means that at Fort Bay 20-30 colonies of protected coral species will be relocated, while at Black Rocks 246 colonies of protected coral species will be relocated (in the base case with berm breakwater). If the choice is made for a caisson structure 200 colonies need to be relocated, in case of a cofferdam structure 144 colonies.

The colonies and specimens of species without a protection status will not be relocated. This means that in both locations hard corals, soft corals, sponges, sea urchins, and other benthos will be lost. This loss is particularly significant in the case of the harbor development at Black Rocks (estimated several hundreds of coral colonies and sponges in the high risk area).
This loss can be partly compensated by enhanced recruitment and settlement of corals[6], but it will take many years (to decades) to restore a complete reef.

Sedimentation from terrestrial sources

Erosion and sedimentation are already ongoing processes in the south coast of Saba, taking serious proportions. Especially the watershed area in which the current stone mine is located, is heavily impacted by erosion, not only from the mine itself but because of the maze of unpaved roads in the direct vicinity. Unpaved roads are one of the major contributors to sedimentation in the Caribbean, contributing 10.000x more than vegetated areas.

The redevelopment of Fort Bay will have only modest impacts on sedimentation from terrestrial sources. For a new stretch of road, a surface of approximately 2.400 m2 (80x30m) needs to be cleared from vegetation. At Black Rocks, a surface of approximately 22.000 m2 needs to cleared from vegetation (road, weirs, harbor area).
This deforestation will lead to severe erosion and sedimentation in the short term. In the long term (3+ years), this impact can partly be mitigated by stabilization of soils and revegetation. On the longer term, if this reforestation is extended to surfaces that are already exposed in the current situation, erosion and sedimentation could be less than in the current, unfavorable situation. However, utmost caution should be exercised because in the long term sources of erosion and sedimentation will remain to exist: a future harbor area in Black Rocks will be a dynamic area, with both built-up areas[7] and areas sensitive to erosion such as unpaved areas, storage areas, scrap yards, urban wastelands, etc.[8]

Sedimentation from marine sources

Impacts on nearby reefs from sedimentation by construction of breakwaters, by land reclamation and by dredging are considered “low” in the Fort Bay project, and “moderate-low” for most patch reefs at Black Rocks (“moderate” for patch reef 2).

Acoustical impacts and disturbance

Significant disturbance for a colony of red-billed tropicbird may be expected during the earth works for the northern weir at Black Rocks (at 50-60 meters altitude), even after impact mitigation. These type of works are not foreseen in the Fort Bay project.

If the selected construction method at Black Rocks would be the cofferdam structure, which is based on impact driving, noise levels for marine organisms (including sea mammals) would be more or less comparable at both locations, but the duration of impact would be 3 times longer at Black Rocks (4

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[6] E.g. by means of the Reef Guard/Coral Engine developed by CSIRO, Delft University of Technology and partners from the private sector

[7] Built-up areas are not necessarily sensitive to erosion but produce run-off with high velocities

[8] Land conversion from forest/orchard to built-up and wasteland lead to the most significant increase of erosion and sedimentation (Li et al, 2013)

months at Black Rocks versus 5/6 weeks at Fort Bay). This would lead to significantly more noise impact (and potential harm) for marine organisms.
For the red-billed tropicbird the same is true with respect to duration, but noise levels at the location of the colony are expected to be slightly less in case of the Fort Bay development, because of the larger distance[9].

Landscape degradation and future urban development

Both landscape degradation and future urban development are significant in case of development of Black Rocks Harbor. In case of redevelopment of Fort Bay Harbor, these impacts are insignificant.

Dive sites

Two popular dive sites will be lost in case of the Black Rocks development: Giles Quarter Shallows and Greer Gut. In case of the redevelopment of Fort Bay Harbor no dive sites are under threat.

Conclusion

In the Black Rocks harbor development the caisson breakwater is the preferred construction method from an ecological point of view because it guarantees a relatively small footprint in an area rich in protected corals. At the same time noise impacts are at an acceptable level. In the Fort Bay harbour reconstruction, the cofferdam is the only feasible construction for the primary breakwater., while for the secondary breakwater the caisson structure is preferred from an ecological point of view.

In general it can be stated that the ecological impacts of the harbor development at Black Rocks are significantly higher -in a number of cases even an order of magnitude higher- than the impacts at Fort Bay in case of the renovation of the harbor, of which the impacts are generally moderate to low, or even insignificant.

Main recommendation

From an environmental and ecological viewpoint it is recommended to renovate the harbor at Fort Bay instead of constructing an entirely new harbor at Black Rocks/Giles Quarter. It is recommended to prepare a new harbor design for Fort Bay, that meets the same requirements for hurricane safety and future capacity as does the design at Black Rocks.
It is recommended to carry out an ecosystem valuation study of the Black Rocks area, in order to quantify its economic potential as a nature area (both terrestrial and marine). This study may also shed light on ecologically friendly development options.

If however the political choice is made for harbor development at Black Rocks, it is strongly recommended to elaborate and implement all proposed mitigation measures, and start an extensive ecological compensation campaign.

[9] Distance between Black Rocks and St. John's Cliffs colony: 600m. Distance between Fort Bay and Great Level colony: 600m.